Seeding and transplanting rare Willamette Valley prairie plants for population restoration

Final Report

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PREFACE

This report is the result of a cooperative Challenge Cost Share project between the Institute for Applied Ecology (IAE) and a federal agency. IAE is a non-profit organization dedicated to natural resource con-servation, research, and education. Our aim is to provide a service to public and private agencies and individuals by developing and communicating information on ecosystems, species, and effective management strategies and by conducting research, monitoring, and experiments. IAE offers educational opportunities through 3-4 month internships. Our current activities are concentrated on rare and endangered plants and invasive species.

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TABLE OF CONTENTS

PREFACE . . . i
ACKNOWLEDGMENTS . . . i
LIST OF FIGURES . . . iv
LIST OF TABLES . . . v
EXECUTIVE SUMMARY . . . 1

INTRODUCTION . . . 5
METHODS . . . 6
- Study species . . . 6
- Field sites . . . 7
- Overview . . . 9
- Direct seeding at Greenhill Road – *Aster, Erigeron, Horkelia,* and *Lomatium* . . . 9
- Transplanting at Greenhill Road – *Lupinus* . . . 11
- Transplanting at Greenhill Road – *Aster, Erigeron, Horkelia,* and *Lomatium* . . . 11
- Transplanting at Greenhill Road – *Erigeron* and *Horkelia* arrays . . . 12
- Direct seeding at Balboa and Rosy – *Horkelia* and *Lomatium* . . . 13
- Transplanting at Balboa and Rosy – *Lomatium* . . . 13
- Transplanting at Balboa – *Lupinus* . . . 13
- Direct seeding at Isabelle – *Lupinus* . . . 14
- Transplanting at Isabelle – *Lupinus* . . . 14
- Transplanting at 1135 – *Lupinus* . . . 14
- Transplanting at Oxbow – *Lupinus* . . . 14
- Direct seeding at Beaver Run – *Aster* . . . 14
- Transplanting at Beaver Run – *Aster* . . . 15
- Direct Seeding at Coble – *Lupinus* . . . 15
- Transplanting at Coble – *Lupinus* . . . 16

RESULTS . . . 16
- Direct seeding . . . 16
  - Greenhill Road – *Aster, Erigeron, Horkelia,* and *Lomatium* . . . 16
  - Balboa and Rosy – *Horkelia* and *Lomatium* . . . 20
  - Isabelle – *Lupinus* . . . 23
  - Coble – *Lupinus* . . . 25
  - Beaver Run – *Aster* . . . 25
- Transplanting . . . 27
  - Greenhill Road, 20x30 m grid – *Aster, Erigeron, Horkelia* and *Lomatium* . . . 27
  - Greenhill Road −*Erigeron* and *Horkelia* arrays . . . 45
  - Balboa & Rosy – *Lomatium* . . . 47
  - Balboa, 1135, and Oxbow West – *Lupinus* . . . 50
  - Greenhill Road – *Lupinus* . . . 51
  - Isabelle – *Lupinus* . . . 52
  - Coble– *Lupinus* . . . 56
  - Beaver Run – *Aster* . . . 57

SUMMARY AND DISCUSSION . . . 66
Direct seeding vs. transplanting . . . 66
Comparison of source populations . . . 68
Effects of competition . . . 68
Effects of fertilizer and other soil amendments . . . 70
Comparison of planting season . . . 71
Effects of topographic position . . . 72
Recommendations . . . 72
LITERATURE CITED . . . 74
Appendix I . . . 76

LIST OF FIGURES

Figure 1. Seed collection sites for rare Willamette Valley prairie species

Figure 2. Number of (a) *Aster curtus*, (b) *Horkelia congesta*, and (c) *Lomatium bradshawii* plants in Greenhill Road seeding plots.

Figure 3. Proportion of *Aster curtus* transplants that survived in the Greenhill 20x30 m grid by (a) fertilizer treatment, (b) seed source, and (c) planting season.

Figure 4. Proportion of *Aster curtus* transplants that were reproductive in the Greenhill 20x30 m grid by (a) fertilizer treatment, (b) seed source, and (c) planting season.

Figure 5. Proportion of *Erigeron decumbens* transplants that survived in the Greenhill 20x30 m grid by (a) fertilizer treatment, (b) seed source, and (c) planting season.

Figure 6. Proportion of *Erigeron decumbens* transplants that were reproductive in the Greenhill 20x30 m grid by (a) fertilizer treatment, (b) seed source, and (c) planting season.

Figure 7. Proportion of *Horkelia congesta* transplants that survived in the Greenhill 20x30 m grid by (a) fertilizer treatment, (b) seed source, and (c) planting season.

Figure 8. Proportion of *Horkelia congesta* transplants that were reproductive in the Greenhill 20x30 m grid by (a) fertilizer treatment, (b) seed source, and (c) planting season.

Figure 9. Proportion of *Lomatium bradshawii* transplants that survived in the Greenhill 20x30 m grid by (a) fertilizer treatment and (b) planting season.

Figure 10. Proportion of *Lomatium bradshawii* transplants that were reproductive in the Greenhill 20x30 m grid by (a) fertilizer treatment and (b) planting season.

Figure 11. Proportion of *Erigeron decumbens* transplants that (a) survived and (b) were reproductive in Greenhill Road arrays.

Figure 12. Proportion of *Horkelia congesta* transplants that (a) survived and (b) were reproductive in Greenhill Road arrays.

Figure 13. Proportion of *Lomatium bradshawii* transplants that survived at Rosy and Balboa by (a) seed source, (b) planting site, and (c) soil treatment.

Figure 14. Proportion of *Lomatium bradshawii* transplants that were reproductive at Rosy and Balboa by (a) seed source, (b) planting site, and (c) soil treatment.

Figure 15. Proportion of transplants of *Lupinus sulphureus* ssp. *kincaidii* that survived at

Greenhill Road when (a) fertilized or not and (b) nodulating bacteria was applied or not.

Figure 16. Proportion of transplants of *Lupinus sulphureus* ssp. *kincaidii* that survived at Isabelle when (a) fertilized or not and (b) nodulating bacteria was applied or not.

Figure 17. Proportion of transplants of *Lupinus sulphureus* ssp. *kincaidii* that were reproductive at Isabelle when (a) fertilized or not and (b) nodulating bacteria was applied or not.

Figure 18. Proportion of transplants of *Lupinus sulphureus* ssp. *kincaidii* that survived at Coble by (a) weeding and (b) fertilization treatment.

Figure 19. Proportion of *Aster curtus* spring transplants that survived at Beaver Run.

Figure 20. Proportion of *Aster curtus* spring transplants that were reproductive at Beaver Run**.**

Figure 21. Proportion of *Aster curtus* autumn transplants that survived by (a) seed source and (b) treatment.

Figure 22. Proportion of *Aster curtus* autumn transplants that were reproductive by (a) seed source and (b) treatment.

LIST OF TABLES

Table A. Summary of reintroduction/augmentation protocols for 5 rare prairie plants of western Oregon.

Table 1. List of species included in this study with federal and state protection status.

Table 2. Seed collection sites, population sizes, managing agency, and date of seed collection for the plants included in this study.

Table 3. The study sites with direct seeding and/or transplanting plots.

Table 4. Seeding rates and source populations for each species seeded at Greenhill Road.

Table 5. Plant materials used for transplanting experiments at Greenhill Road.

Table 6. Percent establishment of plants in Greenhill Road seeding plots and ANOVA results.

Table 7. Growth stages of *Lomatium bradshawii* plants in weeded and unweeded seeding plots at Greenhill Road.

Table 8. Percent establishment of plants in seeding plots at Balboa and Rosy and ANOVA

results.

Table 9. Growth stages of *Lomatium bradshawii* plants in seeding plots at Rosy and Balboa.

Table 10. Percent establishment of *Lupinus sulphureus* ssp. *kincaidii* plants in seeding plots at Isabelle and ANOVA results.

Table 11. Percent establishment of *Lupinus sulphureus* ssp. *kincaidii* plants in seeding plots at Coble and ANOVA results.

Table 12. Effects of fertilizer, planting season, seed source, competition, and topographic position on survival of transplants in the 20x30 m grid at Greenhill Road in 2003.

Table 13. Effects of fertilizer, planting season, seed source, competition, and topographic position on flowering response of transplants in the 20x30 m grid at Greenhill Road in 2003.

Table 14. Growth stages of *Lomatium bradshawii* transplants in the Greenhill Road 20x30 m grid.

Table 15. Growth stages of *Lomatium bradshawii* transplants at Rosy and Balboa.

Table 16. Mean measurements of *Lupinus sulphureus* ssp. *kincaidii* transplants at Isabelle.

Table 17. Mean number of *Lupinus sulphureus* ssp. *kincaidii* leaves per transplant at Coble and ANOVA results.

Table 18. Mean measurements of *Aster curtus* spring transplants at Beaver Run

Table 19. Mean measurements of *Aster curtus* autumn transplants at Beaver Run.

EXECUTIVE SUMMARY

Prairies and oak savannah habitats once dominated the valleys and foothills in western Oregon and southwestern Washington. Fire suppression, invasive species, and habitat loss have substantially reduced the quantity and quality of this habitat. Several plant species of this ecosystem are considered rare, threatened or endangered. Their survival may depend reintroduction and population augmentation, as well as habitat protection and targeted management. Here we report findings from a series of experiments which tested the best methods for reintroducing or augmenting 5 rare species: *Aster curtus, Erigeron decumbens* ssp. *decumbens*, *Horkelia congesta* ssp. *congesta*, *Lomatium bradshawii,* and *Lupinus sulphureus* ssp. *kincaidii*. This executive summary condenses 5 years of research at 7 sites into straight forward recommendations for each species. Detailed experimental results showing how we arrived at these recommendations can be found in the succeeding chapters.

The goal of this study was to establish reintroduction protocols for five rare prairie species of western Oregon:

- *Aster curtus* (white-top aster)
- *Erigeron decumbens* (Willamette fleabane)
- *Horkelia congesta* (Sierra horkelia)
- *Lomatium bradshawii* (Bradshaw's desert parsley)
- *Lupinus sulphureus* ssp. *kincaidii* (Kincaid's lupine)

Summary of experimental methods

Experiments were conducted at seven study sites within the West Eugene Wetlands–1135 Terry St., Beaver Run (including the Rosy unit), Balboa, Coble/Turtle Swale, Greenhill Road, Isabelle, and Oxbow West – from 1999 to 2004. Experiments tested the following factors:

- **Planting method**
  - Seed scarification
  - Direct seeding
  - Transplanting
  - Planting date
- **Source population**
- **Environmental factors**
  - Wetland vs upland (Kincaid's lupine only)
  - Topographic position (microsites within wetlands)
  - Fertilization
- **Density of competing vegetation**

Recommendations for reintroduction/augmentation are described below, and are summarized in

Table A.

- *A. curtus*: Transplant in fall in wetland sites outside of vernal pools. With this protocol, up to 42% of transplanted *Aster curtus* survived 4 years. Direct seeding is not recommended; it produced only 1-2 % establishment. Fertilizer reduced survivorhips at one site but increased flowering at another. Overall, we recommend fertilizing only in low competition environments.
- *E. decumbens*: Transplant in spring in wetland sites outside of vernal pools without fertilizer. This protocol yielded establishment rates of up to 55% after 4 years. Direct seeding produced <0.5% establishment and is not recommended.
- *H. congesta*: Transplant without fertilizer in wetland sites outside of vernal pools in spring. Success rates with this method ranged from 38% to 83% survival after 4 years. Direct seeding can produce a few recruits; however seeding was only marginally effective (up to 4% establishment when combined with weeding).
- *L. bradshawii*: Seed in wetlands without fertilizer in fall after removing or reducing competing vegetation. This protocol produced up to 37% establishment after 4 years. Transplanting works well in fall without fertilizer, especially in wetter sites with weeds eliminated. However, the gain in establishment (40-70% after four years) may not outweigh the increased labor involved.
- *Lupinus sulphureus* ssp. *kincaidii*: Success rates for this species are variable, and likely depend on seasonal climate and local site characteristics such as abundance of weedy vegetation, soil type and hydrology, and soil microorganisms (mycorrhizae and/or *Rhizobium*). Our best recommendations to date are to seed in fall in upland sites with little competing vegetation, especially grasses and aggressive weeds. Transplanting may work, but only in well-restored native prairie with minimal weed densities, especially grasses and aggressive weeds. No fertilization is necessary but *Rhizobium* may increase flowering in the long term.

In addition to the species specific recommendations, we stress the importance of site selection and site preparation. Sites for reintroduction should be similar to habitats where the species currently thrives, and weed abundance should be kept low. Reintroducing species to multiple sites provides the best potential for species recovery.

All five of these rare species can be successfully reintroduced or increased in abundance using the protocols described above. Seedlings were observed near some *E. decumbens* and *H. congesta* transplants after four years and new seedlings have appeared in *L. bradshawii* seeding plots after five years, suggesting that viable seed can be produced in a new population within a short time period. Fender’s blue butterfly eggs were observed on both seeded and transplanted populations of *L. sulphureus* ssp. *kincaidii*, thus both propagation methods produce acceptable lupine habitat for the butterfly.

Table A. Summary of reintroduction/augmentation protocols for 5 rare prairie plants of western Oregon, based on 5 years of research at 7 sites in the west Eugene wetlands.

Species	Seed or transplant	Planting season	Fertilizer	Weeding	Wetland or upland	Topographic position (microsite within wetlands)	Other suggestions
Aster curtus	Transplant	Fall	Generally none; fertilize only in low competition environments	Weeding unnecessary	Wetland	Outside vernal pools	None
Erigeron decumbens	Transplant	Spring	None	Weeding unnecessary	Wetland	Outside vernal pools	None
Horkelia congesta	Transplanting recommended	Spring	None	Weeding unnecessary	Wetland	Outside vernal pools	Seed sources may differ slightly
	Seeding may work	N/A	None	Remove or reduce competing vegetation prior to seeding	Wetland	N/A	None
Lomatium bradshawii	Seed	Fall	None	Remove or reduce competing vegetation prior to seeding	Wetland	N/A	None

	Transplanting also works	Fall	None	Low veg. cover good for transplants	Wetland	Vernal pools	None
Lupinus sulphureus ssp. kincaidii	Seed	Fall	None	Seed into sites with little competing vegetation	Upland	N/A	Seed scarification unnecessary
	Transplant only in high quality prairie (low weed abundance)	Fall	None	Low weed abundance prior to planting necessary	Upland	N/A	*Rhizobium* may increase flowering

INTRODUCTION

Seedling of *Lomatium bradshawii* recently emerged from its seed coat.

Habitat restoration, population enhancement, and reintroduction are management tools of increasing importance for rare species conservation. Reintroduction, in particular, may be essential for endangered plant conservation, especially for species with few remaining wild populations (Falk, Millar and Olwell 1996). However, techniques for propagating rare species are seldom well developed, and thus pose a challenge to restoration projects; seed germination tests and vegetative propagation trials for few rare plants have been conducted. Although reintroduction is underway for some plant species, the field is in its infancy. In a bibliography of 600 published accounts and grey literature on plant reintroduction and restoration (Atkinson, Maunder and Walter 1995), only about 10% were detailed re-introduction case histories. Effective procedures for rare plant propagation and establishment are crucial for advancing the practice of species restoration and are important components of conservation plans for western prairie species (Thomas and Carey 1996).

Grasslands and oak savannahs were once dominant vegetation-types of interior valleys and foothills in western Oregon and southwestern Washington. This prairie-savannah ecosystem was widespread before fire suppression and settlement in the late 1800s (Habeck 1961, Johanesson *et al.* 1977). Prior to Euro-American settlement, these prairies were maintained by frequent fires set by local native American groups to promote food plants, such as camas (*Camassia quamash* and *C. leichtlinii*), and to herd game to improve hunting success (Johanesson et al. 1977). Today, less than one percent of presettlement-composition prairies remain, and tools for managing this habitat for native and endangered species are urgently needed (Wilson et al. 1995).

Several plant species of this ecosystem are considered rare, threatened or endangered. Their survival may depend on adequate habitat protection and optimal management, as well as targeted population enhancement and reintroduction through seeding and transplanting of *ex situ*-cultivated plant materials. The objective of this progress report is to evaluate field seeding and planting of greenhouse grown plants as methods of establishing new populations of rare species. A previous report documenting results of germination tests of the same plants is also available (Kaye and Kuykendall 2000). The focus species for this study include *Aster curtus, Erigeron decumbens* ssp. *decumbens*, *Horkelia congesta* ssp. *congesta*, *Lomatium bradshawii*, and *Lupinus sulphureus* ssp. *kincaidii* (Table 1).

Table 1. List of species included in this study with federal and state protection status.

Species	Federal status	State status
Aster curtus	species of concern	candidate
Erigeron decumbens ssp. *decumbens*	endangered	endangered
Horkelia congesta ssp. *congesta*	species of concern	candidate
Lomatium bradshawii	endangered	endangered
Lupinus sulphureus ssp. *kincaidii*	threatened	threatened

METHODS

Study species

All of the species included in this study occur in western Oregon prairies, and three of them, *Aster curtus*, *Lomatium bradshawii* and *Lupinus sulphureus* ssp. *kincaidii*, also occur in western Washington. Seeds for germination experiments were collected from several sites in the Eugene area, primarily from lands managed by the Eugene District, Bureau of Land Management (BLM) and the U.S. Army Corps of Engineers (ACOE). These sites included Fisher Butte Management Unit, Greenhill Road, Oxbow West, Royal Amazon South Management Unit, Balboa, and Fir Butte (Table 2). At each site, seeds were collected from over twenty individuals and pooled. No effort was made to keep track of seed families. Seeds were cleaned by hand or by sieve and blower to select only those that appeared filled and healthy.

Table 2. Seed collection sites, population sizes, managing agency, and date of seed collection for the five rare plants of western Oregon prairies included in this study. See Figure 1 for site locations.

Species	**Source population (size, management)**	**Date collected**
Aster curtus	Greenhill Road (BLM) Balboa (BLM)	10/15/99 10/15/99
Erigeron decumbens	Fisher Butte (2500, ACOE) Greenhill Rd (355, BLM) Oxbow West (2000, BLM)	7/20/99 7/20/99 7/20/99
Horkelia congesta	Fisher Butte (300-500, ACOE) Greenhill Rd, south of RR tracks (500-1000, private)	8/19/99 8/19/99

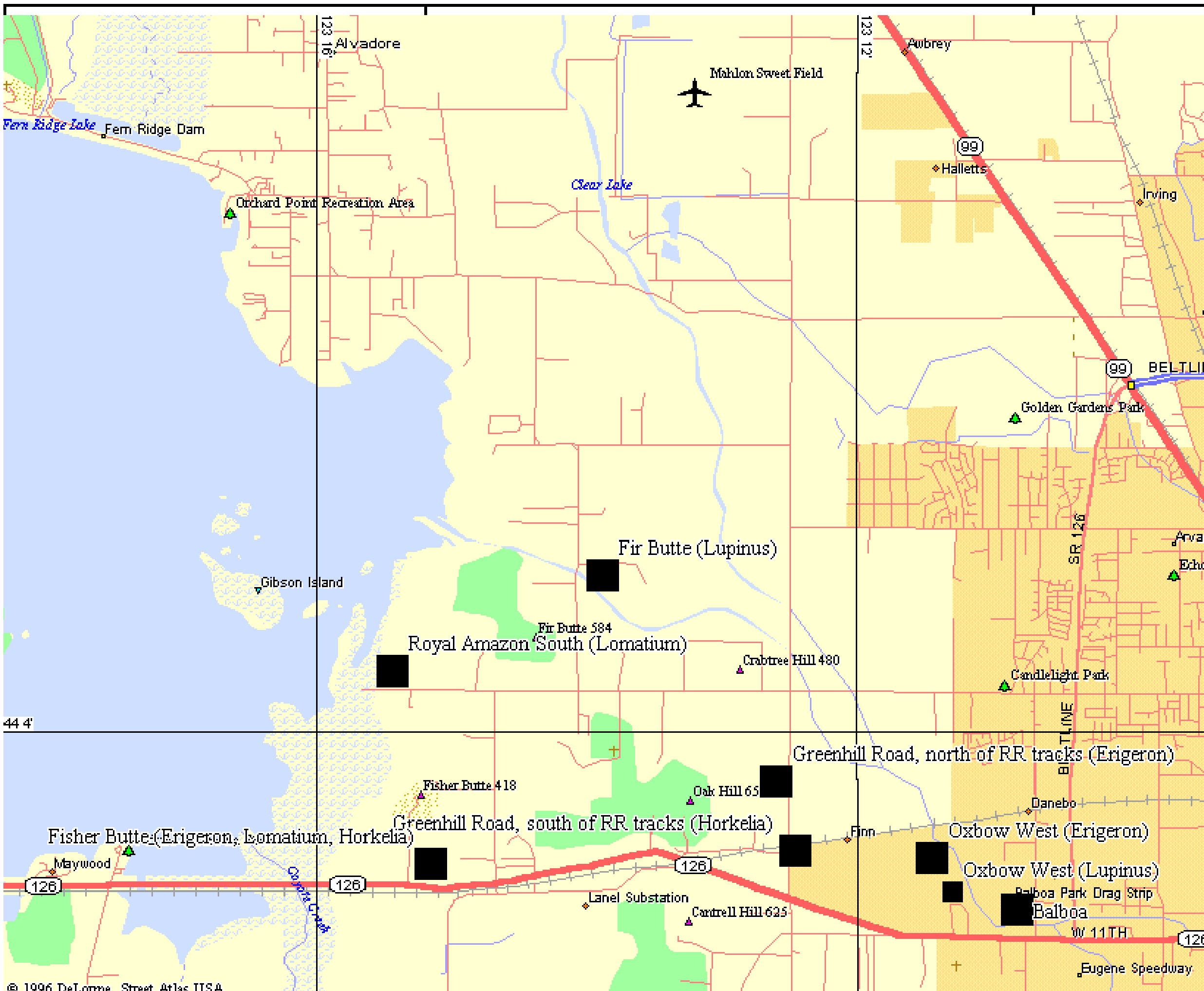


Figure 1. Seed collection sites for germination and propagation tests with rare Willamette Valley prairie species (scale: 1.25 cm = 1 km).

Lomatium bradshawii	Fisher Butte (>5000, ACOE) Royal Amazon South (>5000, ACOE)	7/7/99 6/29/99
Lupinus sulphureus ssp. *kincaidii*	Oxbow West (~60, BLM) Fir Butte (1000-2000, BLM)	7/20/99 7/20/99

Field sites

Field propagation was conducted at several sites in the west Eugene area (Table 3). See

Appendix I, Documentation Packet, for information on the location of each of these sites. All of the sites are locations of ongoing habitat restoration projects.

Table 3. Sites with plots established to test the effectiveness of direct seeding and/or transplanting of *ex situ* propagated plants as methods of establishing or enhancing populations.

Site	**Species**	**Seeding?**	**Transplant?**
Greenhill Road	*Aster curtus* *Erigeron decumbens* *Horkelia congesta* *Lomatium bradshawii* *Lupinus sulphureus* ssp. *kincaidii*	yes yes yes yes no	yes yes yes yes yes
Balboa and Rosy	*Horkelia congesta* *Lomatium bradshawii* *Lupinus sulphureus* ssp. *kincaidii*	yes yes no	no yes yes
Isabelle	*Lupinus sulphureus* ssp. *kincaidii*	yes	yes
Beaver Run	*Aster curtus*	yes	yes
1135	*Lupinus sulphureus* ssp. *kincaidii*	no	yes
Oxbow West	*Lupinus sulphureus* ssp. *kincaidii*	no	yes
Coble/Turtle Swale	*Lupinus sulphureus* ssp. *kincaidii*	yes	yes

Overview

To compare direct seeding and transplanting as methods of establishing rare plants, we initiated a series of experiments at seven locations in the west Eugene area. In addition to evaluating direct seeding, some of these experiments addressed the usefulness of adding fertilizer or other amendments (such as Rhizobium to the lupines) to transplants, identifying the effects of microsite or competing vegetation abundance on plant establishment and growth, and importance of spring vs. autumn planting seasons. These experiments are described below.

Direct seeding at Greenhill Road – *Aster, Erigeron, Horkelia,* and *Lomatium*

To assess the efficiency of direct seeding for *Aster curtus*, *Erigeron decumbens*, *Horkelia congesta*, and *Lomatium bradshawii*, 10 plots were established in the restoration area at Greenhill Road. The plots were randomly placed, marked with wood posts, and five were selected at random for removal of established vegetation to create a surface of bare soil. Each plot was 1 x 4 m, and each species was assigned to a 1 x 1 m portion of each plot. All plots were established and seeded on 11/19/99. See Table 4 for seeding rates and sources. Seedlings were counted in each plot in 2000-2004 and measurements were taken in 2003 and 2004. *L. bradshawii* plants were described by growth stage in 2003 and 2004: seedling = cotyledons present, V1-V2 = 1-2 leaves, V3+ = 3 or more leaves, R1 = 1 inflorescence, R2 = 2 inflorescences, R3 = 3 or more inflorescences.

Table 4. Seeding rates and source populations for each species seeded at Greenhill Road.

Species	No. seeds per plot	Seed source (collection date)
Aster curtus	50	Greenhill Road (10/15/99)
Erigeron decumbens	60	Oxbow West (7/20/99)
Horkelia congesta	100	Greenhill Road (8/19/99)
Lomatium bradshawii	60	Fisher Butte (7/7/99)

Transplanting at Greenhill Road – *Lupinus*
To evaluate the effects of fertilizer and nodulating bacteria, 60 lupine plants were transplanted into three 3 x 4 m plots, with 20 transplants per plot, on 3/28/00. Plants were spaced 1 m apart and each was marked with a blue flag to the north of the plant. Each plant was randomly assigned to a fertilizer and a *Rhizobium* treatment in a 2 x 2 factorial design. The fertilizer treatment consisted of 2 teaspoons of 17-17-17 slow release fertilizer (Schultz multi-cote time-release outdoor plant food, "releases primary nutrients continuously for up to 4 months at 70 F," which also contained sulphur [3.8%], iron [0.3%], and manganese [0.06%]), and *Rhizobium* was added at the rate of 1 tsp per plant. We used a *Rhizobium* isolated from *Lupinus* by Urbana Labs (*Bradyrhizobium* sp., 2.0 x 10^8 infective viable cells/gram, Lot No. J11). All lupine plant material came from seeds collected at Fir Butte (7/20/99) and grown in 5-in deep pots from December 1999 through March 2000 in a heated greenhouse. Plant establishment and size (number of leaves, plant area) were recorded in 2000-2003. Five transplants were placed on a small hill at the Greenhill Road site as well.

Transplanting at Greenhill Road – *Aster, Erigeron, Horkelia,* and *Lomatium*
A transplanting experiment was initiated with *Aster curtus, Erigeron decumbens, Horkelia congesta,* and *Lomatium bradshawii* on 3/28/00 at Greenhill Road. The goals of this experiment were to measure the effects of source population, fertilizer, planting season (spring or autumn), cover of competing vegetation, and microsite on plant establishment and size. A 20 x 30 m grid was established and plants were planted on 1-m centers. For each transplant location, the total cover of competing vegetation was noted (generally estimated to the nearest 10%), and the microsite was recorded. Microsites were assigned a code of 1–5 based on a field assessment of seasonal moisture and topographic position from high to low. High microsites (with no seasonal pooling or inundation with water) were assigned a code of 1, while low microsites (vernal pools) were given a 5. Microsites on the edge of vernal pools were assigned a 3. Sites intermediate were given 2 or 4, accordingly. For spring transplants, this assignment was made on 5/10/00 after heavy rains and while pond water was present, and on 5/8/01 for plants transplanted in autumn of 2000. Each transplant was randomly assigned to a position in the 20 x 30 m experimental area. Fertilizer (17-17-17 slow release) was applied at the rate of 2 tsp per plant (see description of fertilizer above) at the time of transplanting. Autumn transplants were grown in pots throughout the summer of 2000 and planted on 10/26/00. During summer cultivation, the

autumn transplants were watered daily and fertilized monthly with liquid fertilizer. See Table 5 for information on source populations and cultivation of each species used in this experiment. Transplants were monitored in 2000-2004 to record plant establishment, size, and reproduction. The number of seedlings present around each reproductive transplant was recorded in 2003 and 2004.

Table 5. Plant materials used for transplanting experiments at Greenhill Road.

Species	**Source population (seed collection date)**	**Cultivation history (original potting date)**
Aster curtus	Greenhill Road (10/15/99) Balboa (10/15/99)	Grown from 12/8/99 (spring); 1/29/00 (autumn) Grown from 2/15/00 (autumn transplants); 2/24/00 to 3/19/00 (autumn)
Erigeron decumbens	Greenhill Road (7/20/99) Oxbow West (7/20/99) Fisher Butte (7/20/99)	12/16/99 to 1/12/00 (spring); 1/21/00 to 2/7/00 (autumn) 12/8/99 to 1/12/00 (spring); 2/10/00 to 3/11/00 (autumn) 12/8/99 to 1/12/00 (spring); 2/10/00 to 3/11/00 (autumn)
Horkelia congesta	Greenhill Road (8/19/99) Fisher Butte (8/19/99)	12/16/99 to 1/12/00 (spring); 2/10/00 to 3/11/00 (autumn) 12/16/99 to 1/12/00 (spring); 2/9/00 to 3/10/00 (autumn)
Lomatium bradshawii	Fisher Butte (7/7/99)	Grown from 12/15/99 (spring & autumn transplants), 9-in pots

Transplanting at Greenhill Road – *Erigeron* and *Horkelia* arrays

To evaluate the effects of mixed source populations on seed set and long-term seedling recruitment, we initiated a pilot study with *Erigeron decumbens* and *Horkelia congesta* on 10/26/00. For *Erigeron*, the sources were Oxbow West and Greenhill Road. Fisher Butte and Greenhill Road were the sources for the *Horkelia*. Plants were placed in arrays dispersed throughout the restoration site, each array no closer than 30 m to each other or the other transplant plots at this site. Arrays consisted of 6 plants of each species planted in a ring (on the points of a hexagon) with 0.75 m between adjacent plants so that each plant was the same distance to all others. There were three types of arrays: 1) three plants from each of two sources, 2) six plants from a single source, and 3) six

A young transplant of *Horkelia congesta* at the Greenhill Road restoration site.

plants from the other single source. Nine arrays (three of each type) were established containing *Horkelia* and *Erigeron* (off-set from one another so that each array accommodated two species), plus three more arrays (one of each type) with *Horkelia* only. Thus, there were a total of 12 array plots, 9 of which contained both species. Each plant was marked with a yellow flag and arrays were marked in the center by a wood post. Measurement data and number of inflorescences was recorded from these transplants in 2001-2004 and number of seedlings around each reproductive transplant was recorded in 2003 and 2004.

Direct seeding at Balboa and Rosy – *Horkelia* and *Lomatium*

Direct seeding was conducted at the Rosy and Balboa sites on 11/12/99. These sites were prepared and seeded with native plants in summer and autumn of 1999 prior to our seeding. The sites were further prepared through various soil amendments conducted in a randomized block design, with four blocks (two at Rosy and two at Balboa). Randomly assigned plots (10 x 40 m, ~1/8 acre) in each block were given fertilizer (12-13 lbs), organic material (compost,"biosolids," 1.5 cubic yds), mycorrhizae (2-3 lbs), mycorrhizae and compost, or nothing (control). These amendments were conducted on 10/14/99 and 10/19/99.

Within each treatment plot, three 1 x 2 m subplots were established and marked with wood posts. Half of each plot (1 x 1 m area) was seeded with *Lomatium bradshawii* (75 seeds/plot, collected from Royal Amazon South 6/29/99) and half was seeded with *Horkelia congesta* (100 seeds/plot, Greenhill Road 8/19/99). Thus, a total of 15 subplots per block were established, or 60 subplots overall. Seedlings were counted in each plot in 2000. Measurement data were taken on *Horkelia* plants in 2001-2004. The growth stages of *Lomatium* plants were recorded in 2001-2004.

Transplanting at Balboa and Rosy – *Lomatium*

The seeding subplots described above were used to locate planting locations for additional transplants of *Lomatium bradshawii*. At Balboa, these transplants were centered at either end of the 1 x 2 m subplots, fertilized with 1 tsp 17-17-17 slow release fertilizer, marked with a blue flag 10-cm north, and planted on 3/24/00. Half the transplants were from Royal Amazon South (collected 6/29/99 and potted 12/16/00, 5-in pots) and half were from Fisher Butte (collected 7/7/99 and potted 12/16/00, 5-in pots). At Rosy, the transplants followed the same scheme and methods, except no transplants from Royal Amazon South were planted, so only one transplant was placed at each subplot (on the north end). Survival of the transplants was recorded in 2000 and the growth stage of each was recorded in 2001-2004.

Transplanting at Balboa – *Lupinus*

We planted lupines on an upland bank at the north end of Balboa on 3/23/00. Plants were placed in four rows, with row 1 across the bottom of the slope and row 4 across the top of the slope. The rows were placed 1.5 m apart, and plants were spaced along the rows at 2-m intervals. A total of 60 transplants were planted, and all of them were fertilized with 2 tsp of 17-17-17 slow release fertilizer. All transplants were grown from seed collected at Fir Butte (7/20/00), potted 12/10/99 and grown in 9-in pots. Wood posts marked the ends of the rows and blue flags marked each plant. Plant area, number of leaves, and number of inflorescences were recorded in

2000 and 2001.

Direct seeding at Isabelle – *Lupinus*
Ten plots were established along the top of an upland bank at Isabelle on 11/19/99. These plots were seeded with lupine seeds in a split design to test for effects of removing competing vegetation and scarifying seeds. Half of the plots were stripped of existing vegetation to create bare soil, while the other five plots were not disturbed. The plots were 1 x 2 m and each 1 x 1 m half of the plot was randomly assigned scarified or unscarified seeds. Seeds were scarified prior to sowing by slitting the seed coat with a razor blade. A total of 50 seeds were sown in each half of each plot. All seeds came from Fir Butte (collected 7/20/99). Twelve additional plots were established adjacent to the existing plots, five of which were scraped clear of vegetation, and seeded on 2/7/03. The number of seedlings in each plot was recorded in 2000 and the size of the plants recorded in 2001-2004.

Transplanting at Isabelle – *Lupinus*
To test for the effects of fertilizer, nodulating bacteria, and topographic position on plant establishment and growth, transplants were randomly assigned these treatments and positions in a 2x2x4 factorial design. Four topographic positions were identified, base of slope (position 1, wetland), lower-middle (2), upper-middle (3), and top (4), and plants within these positions were either fertilized (2 tsp 17-17-17 slow release fertilizer), provided *Bradyrhizobium* sp. (1 tsp), or both. A total of 128 plants were placed at this site, spaced 2-m apart. Transplants were planted on 3/23/00 and came from seeds collected at Fir Butte (7/20/00) and potted in 9-in pots (12/10/00). Each transplant was marked with a blue flag 10-15 cm north of the plant. Transplants were monitored in 2000-2004 for plant size (area and number of leaves).

Transplanting at 1135 – *Lupinus*
The experimental design at this site was very similar to the lupine transplanting at Isabelle. Four topographic positions (rows) of plants were established, the first at the bottom of a slope (position 1) and the others across the hillside at increasing elevation, with position 4 at the top of the slope. These rows were 20 m long, with plants placed each meter, for a total of 80 plants. Transplants were randomly assigned a fertilizer and/or nodulating bacteria treatment, for a 2x2x4 factorial design. Transplants came from seed collected at Fir Butte (7/20/99) and grown in 9-in pots from 12/16/00. A total of 12 randomly placed plants came from Oxbow West seeds (7/20/00). Transplanting was conducted 3/30/00 and plants were monitored in 2000 and 2001.

Transplanting at Oxbow – *Lupinus*
A small number of lupine transplants were placed near the existing Oxbow West population of *Lupinus sulphureus* ssp. *kincaidii*. These transplants were grown from seed in 9-in pots, and all seeds were collected from the adjacent population on 7/20/00 and potted on 1/17/00. Transplanting occurred on 4/3/00. Plants were watered in, but no fertilizer or nodulating bacteria were added. A total of 11 plants were placed in a grid with 1-m spacing, and each plant was marked with a wood stake. Measurement data was taken in 2000-2004.

Direct seeding at Beaver Run – *Aster*

Aster curtus was seeded into plots at Beaver Run on 11/12/99 to evaluate the effectiveness of direct seeding as a technique for establishing plants. Ten plots were established, five in a restored habitat that had been reworked and seeded the prior year, and five in an undisturbed prairie dominated by *Deschampsia cespitosa*. Each plot was 1 x 2 m, split into two 1 x 1 m subplots. Each subplot was randomly assigned to a treatment of vegetation removal or non disturbance (control) and seeded with 50 *Aster curtus* seeds. Further evaluation of the seeds used in this test revealed that only 37% contained fully developed embryos, so the total number of viable seeds placed in each subplot was approximately 18. The seeds were collected from Balboa patches 4 and 10 on 10/99. Attempts were made to obtain seeds from the local patches of *Aster curtus* that already existed at this site, but no seeds collected from this location contained embryos. The number of seedlings in each plot was recorded in 2000 and the surviving plants were measured in 2001-2004.

Transplanting at Beaver Run – *Aster*

Aster curtus transplanting at Beaver Run was combined with the seeding plots to provide a direct comparison of seeding and transplanting. One transplant was placed adjacent to each subplot but removal of competing vegetation was not complete. Transplants were marked with wooden stakes. These transplants were grown from 3-cm rhizome cuttings obtained from two small clumps of plants collected at the Balboa site in October 1999. In addition, two groups of transplants derived from larger cuttings (>10 cm of rhizome length) were placed, one in an undisturbed *Deschampsia cespitosa* prairie (adjacent to an existing *Aster curtus* patch in hopes of providing outcrossed pollen and increased viable seed set in that patch), and one in the restoration area. Each patch consisted of five plants marked with wood stakes. The transplants were monitored in 2000-2004 by recording plant height, maximum and perpendicular widths, and number of stems and inflorescences.

Aster curtus transplants in pots.

In autumn of 2000 (10/26/00), an additional 80 transplants were placed at this site, divided into groups of 16 and planted in five plots throughout the western half of the site. Each plant was marked with a yellow flag, and half of the plants were randomly assigned a fertilizer treatment (2 tsp 17-17-17 slow release). The plants were grown from seeds collected at Balboa (patches 2, 3, 5, 7, and 8) and Greenhill Road. Each transplant was randomly assigned in an effort to maximize outcrossing because closely related plants tend not to produce viable seeds. The height, maximum and perpendicular widths, and number of stems and inflorescences of these transplants were recorded in 2001-2004.

Direct Seeding at Coble – *Lupinus*

Twenty seeding plots were established on 2/12/02 at randomly chosen locations within two macroplots at Coble to the north and south of the existing wild *Lupinus sulphureus* ssp. *kincaidii* population. Wooden stakes marked the northeastern and southwestern corners of each plot. Plots were designed similarly to those at Isabelle–1 x 2 m plots were scraped or not and half the plot was seeded with 50 scarified seeds, half with 50 unscarified. Ten additional seeding plots were established, none of them scraped, and half seeded with scarified and half with unscarified seeds in 1/2003. The number of lupines present in each subplot was recorded in 2002-2004 and number of leaves per subplot in 2004.

Transplanting at Coble – *Lupinus*

Twenty-six transplanting plots 1 x 1 m in size were also randomly placed within the two macroplots at Coble with wooden stakes marking the northeastern and southwestern corners of each plot. Plots were randomly assigned treatments of scraping, fertilizing (2 tsp Schultz's slow-release plant food), both, or neither. Five lupines were transplanted into each plot on 5/6-5/7/02. Maximum and perpendicular width, number of leaves, inflorescences, and butterfly eggs per transplant were recorded in 2003 and 2004.

RESULTS

Direct seeding

Greenhill Road – *Aster, Erigeron, Horkelia,* and *Lomatium*

Direct seeding was a highly effective method of establishing *Lomatium bradshawii* at Greenhill Road, but it was less successful with the other species investigated at that site. A significantly greater number of *Aster curtus* plants in 2003, *Horkelia congesta* plants in 2002, and *L. bradshawii* plants in 2001-2004 were observed in plots that were weeded before the seeding (Table 6; Figure 2). A weak effect of weeding was observed on the number of *A. curtus* plants in 2004, *H. congesta* plants in 2003 and 2004, and *L. bradshawii* plants in 2000.

The mean maximum width of the three *A. curtus* plants observed in 2003 was 14.33 cm, perpendicular width was 12.00 cm, height was 12.00 cm, number of stems per plant was 8.67, and no capitula were observed. Mean maximum width of the six plants observed in 2004 was 14.83 cm, perpendicular width was 11.83 cm, height was 12.00 cm, and number of capitula per plant was 12.00.

The mean maximum width of the two *E. decumbens* plants observed in 2003 was 12.50 cm, perpendicular width was 10.50 cm, vegetative height was 9.00 cm, flowering height was 17.50 cm, and number of inflorescences per plant was 5.50. Mean maximum width of the three plants observed in 2004 was 10.67 cm, perpendicular width was 8.67 cm, vegetative height was 9.33 cm, flowering height was 13.50 cm, and number of inflorescences was 4.00.

The mean maximum width of the *H. congesta* plants in 2003 was 13.98 cm, perpendicular width was 11.24 cm, vegetative height was 10.09 cm, flowering height was 31.38 cm, and number of inflorescences per plant was 0.69. Mean maximum width in 2004 was 14.50 cm, perpendicular width was 10.72 cm, vegetative height was 7.92 cm, flowering height was 33.95 cm, and number of inflorescences was 1.14. Though reproductive plants were only observed in the weeded plots in both years, none of the plant measurements varied significantly by plot treatment

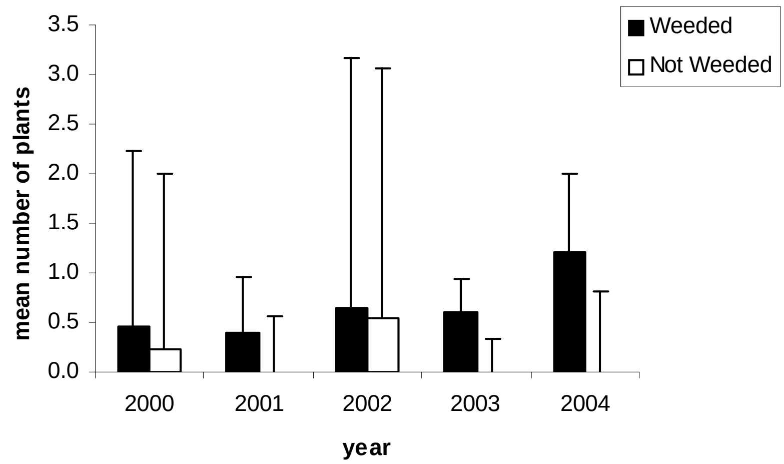
($0.16 < P < 0.99$).

In weeded plots, 4% of *L. bradshawii* plants in 2002, 19% in 2003, and 41% in 2004 were reproductive (Table 7). No reproductive plants were observed in unweeded plots in 2002, but 2% were reproductive in 2003 and 8% in 2004.

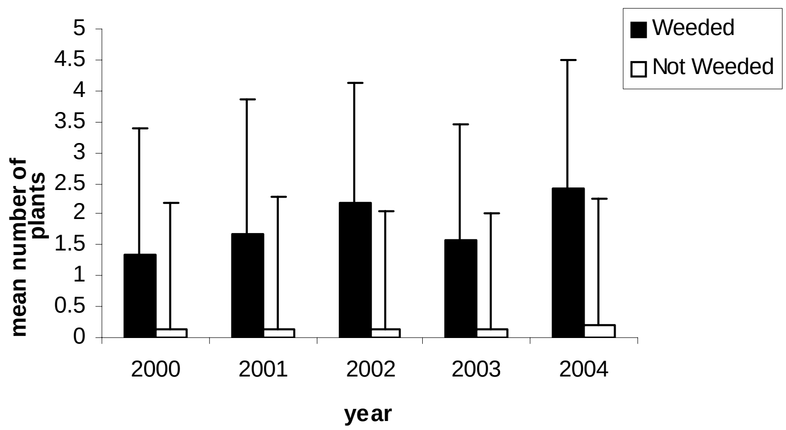
Table 6. Mean percent establishment of plants (with 95% confidence intervals) in 2000-2004 in weeded and undisturbed plots at Greenhill Road seeded with one of four species. P-values are from one-way ANOVA. n=5 weeded and 5 undisturbed plots for each species. Seeds per plot: 50 *Aster curtus*, 60 *Erigeron decumbens*, 100 *Horkelia congesta*, and 60 *Lomatium bradshawii*. (*denotes significance at the 0.05 level; **denotes significance at the 0.01 level; †denotes a weak effect (0.05<*P*<0.1))

Species and year	Weeded	Not weeded	P-value
Aster curtus			
2000	0.94% (-1.92-3.80)	0.48% (-2.38-3.34)	0.58
2001	0.80% (-0.30-1.90)	0.00% (-1.10-1.10)	0.35
2002	1.30% (-3.94-6.54)	1.08% (-4.16-6.32)	0.91
2003*	1.20% (0.52-1.88)	0.00% (-0.68-0.68)	0.04
2004†	2.40% (0.78-4.02)	0.00% (-1.62-1.62)	0.07
Erigeron decumbens			
2000	0.67% (0.10-1.23)	0.00% (-0.57-0.57)	0.14
2001	0.33% (-0.13-0.80)	0.00% (-0.47-0.47)	0.35
2002	0.33% (-0.13-0.80)	0.00% (-0.47-0.47)	0.35
2003	0.67% (0.10-1.23)	0.00% (-0.57-0.57)	0.14
2004	1.00% (0.08-1.92)	0.00% (-0.92-0.92)	0.15
Horkelia congesta			
2000	1.33% (-0.51-3.17)	0.12% (-1.72-1.96)	0.12
2001	1.69% (-0.32-3.70)	0.12% (-1.89-2.13)	0.10
2002*	2.18% (0.50-3.86)	0.12% (-1.56-1.80)	0.03
2003†	1.56% (-0.05-3.17)	0.12% (-1.49-1.73)	0.06
2004†	2.41% (0.34-4.45)	0.19% (-1.88-2.26)	0.05
Lomatium bradshawii			
2000†	36.18% (34.08-38.28)	13.63% (11.53-15.73)	0.05
2001*	30.67% (27.37-33.97)	4.43% (1.13-7.73)	0.02
2002**	36.05% (34.03-38.07)	7.37% (5.35-9.38)	0.004
2003*	34.03% (31.97-36.10)	12.57% (10.50-14.63)	0.03
2004**	37.33% (28.35-46.32)	12.67% (3.68-21.65)	0.005

(a) *Aster curtus*



(b) *Horkelia congesta*



(c) *Lomatium bradshawii*

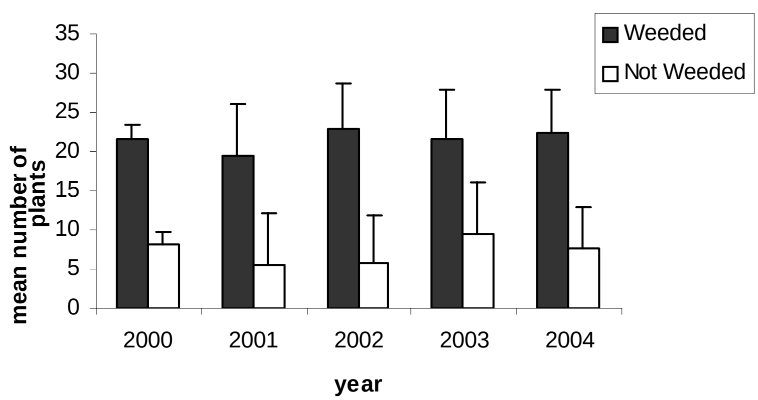


Figure 2. Mean number of plants (± 95% confidence interval) in 2000-2004 in weeded and undisturbed plots at Greenhill Road that were seeded with (a) *Aster curtus*, (b) *Horkelia congesta* and (c) *Lomatium bradshawii*.

Table 7. Growth stages of *Lomatium bradshawii* plants in weeded and unweeded seeding plots at Greenhill Road in 2002-2004. Only seedling and reproductive growth stages were recorded in 2002. (- signifies no data available)

Year	Plot treatment	Growth stage						Total number of plants	
		Seedling	V1-V2	V3+	R1	R2	R3	Vege-tative	Repro-ductive
2002	Weeded	1	-	-	4	1	0	109	5
	Unweeded	0	-	-	0	0	0	29	0
2003	Weeded	0	7	81	16	4	0	88	20
	Unweeded	0	13	34	0	1	0	47	1
2004	Weeded	4	6	56	35	11	0	66	46
	Unweeded	0	7	28	3	0	0	35	3

Balboa and Rosy – *Horkelia* and *Lomatium*
No effect of soil amendments on *Horkelia congesta* or *Lomatium bradshawii* plant establishment in 2000-2004 was detected in ANOVA (Table 8). Seeding appeared more effective for overall recruitment of *L. bradshawii* than *H. congesta*.

The size of *H. congesta* plants in 2001-2004 did not significantly differ by treatment ($0.29<P<0.94$), though a weak effect of treatment on number of inflorescences per plant was observed in 2004 ($P=0.06$). The mean number of inflorescences per plant in each treatment (±95% confidence intervals) was: compost: 0.50±0.58; mycorrhizae: 0.25±0.41; control: 1.17±0.48; and no inflorescences observed in the fertilizer and compost+mycorrhizae treatments. In 2001, the overall mean maximum width of the plants was 3.21 cm, perpendicular width was 1.67 cm, height was 5.85 cm, and number of inflorescences per plant was 0.02. In 2002, overall mean maximum width was 6.95 cm, perpendicular width was 3.71 cm, height was 7.25 cm, and no inflorescences were observed. In 2003, overall mean maximum width was 6.77 cm, perpendicular width was 4.63 cm, vegetative height was 4.68 cm, flowering height was 32.50 cm, and number of inflorescences was 0.04. In 2004, overall mean maximum width was 9.04 cm, perpendicular width was 5.77 cm, and height was 8.83 cm.

The total number of reproductive *L. bradshawii* plants observed was 11 in 2001, 6 in 2002, 17 in 2003, and 28 in 2004. The number of plants observed in each growth stage in 2003 and 2004, as well as the number of each on which grazing was observed, is shown in Table 9.

Table 8. Mean percent establishment of plants (with 95% confidence intervals) in 2000-2004 in plots treated with fertilizer, compost, mycorrhizae, both compost and mycorrhizae, or untreated and seeded with *Horkelia congesta* and *Lomatium bradshawii* at Balboa and Rosy. P-values are from ANOVA with blocking; n=4 for each treatment. Seeds per plot: 100 *H. congesta* and 75 *L. bradshawii*.

Species and year	Fertilizer	Compost	Mycorrhizae	Compost + mycorrhizae	Control	P-value
Horkelia congesta						
2000	7.75% (1.89-13.61)	6.58% (0.72-12.44)	8.83% (2.97-14.69)	8.50% (2.64-14.36)	12.42% (6.56-18.28)	0.71
2001	4.00% (0.36-7.64)	4.92% (1.28-8.56)	5.25% (1.61-8.89)	4.42% (0.78-8.06)	7.17% (3.53-10.81)	0.78
2002	3.33% (0.22-6.44)	1.75% (-1.36-4.86)	6.42% (3.31-9.53)	4.33% (1.22-7.44)	7.67% (4.56-10.78)	0.13
2003	2.67% (-0.57-5.91)	1.17% (-2.07-4.41)	2.42% (-0.82-5.66)	0.42% (-2.82-3.66)	7.08% (3.84-10.32)	0.10
2004	2.42% (-0.68-5.52)	1.58% (-1.52-4.68)	2.42% (-0.68-5.52)	0.67% (-2.43-3.77)	5.75% (2.65-8.85)	0.27
Lomatium bradshawii						
2000	24.77% (10.13-39.41)	24.00% (9.36-38.64)	19.67% (5.03-34.31)	30.89% (16.24-45.53)	27.22% (12.58-41.87)	0.87
2001	10.23% (2.40-18.05)	9.89% (2.07-17.72)	8.89% (1.07-16.74)	8.78% (0.95-16.60)	11.56% (3.73-19.38)	0.99
2002	16.23% (8.13-24.32)	11.77% (3.68-19.87)	13.89% (5.80-21.99)	10.00% (1.90-18.10)	18.11% (10.01-26.21)	0.65
2003	15.00% (6.93-23.07)	14.77% (6.71-22.84)	10.67% (2.60-18.73)	8.11% (0.04-16.18)	20.89% (12.82-28.96)	0.29
2004	14.78% (7.66-21.90)	9.56% (2.44-16.68)	12.56% (5.44-19.68)	7.17% (0.05-14.29)	17.00% (9.88-24.12)	0.37

Table 9. Growth stages of *Lomatium bradshawii* plants observed in 2003 and 2004 in seeding plots at Balboa and Rosy treated with fertilizer, compost, mycorrhizae, both compost and mycorrhizae, or untreated at Balboa and Rosy. The number of plants in each growth stage on which grazing was observed is listed in parentheses.

Year	Plot Treatment	Growth stage						Total number of plants	
		Seedling	V1-V2	V3+	R1	R2	R3	Vegetative	Reproductive
2003	Fertilizer	0	44 (5)	88 (12)	2 (0)	1 (0)	0	132 (17)	3 (0)
	Compost	0	46 (15)	78 (20)	9 (3)	0	0	124 (35)	9 (3)
	Mycorrhizae	0	53 (14)	66 (11)	0	0	0	119 (25)	0
	Compost+ mycorrhizae	0	36 (12)	37 (9)	0	0	0	73 (21)	0
	Control	0	89 (11)	94 (19)	4 (0)	1 (0)	0	183 (30)	5 (0)
2004	Fertilizer	0	44 (1)	78 (7)	11 (0)	0	0	122 (8)	11 (0)
	Compost	0	25 (2)	50 (5)	5 (0)	6 (1)	0	75 (7)	11 (1)
	Mycorrhizae	1 (0)	33 (3)	73 (2)	5 (0)	1 (0)	0	107 (5)	6 (0)
	Compost+ mycorrhizae	0	34 (5)	23 (1)	2 (1)	1 (0)	0	57 (6)	3 (1)
	Control	0	52 (10)	96 (14)	5 (0)	0	0	148 (24)	5 (0)

Isabelle – *Lupinus*

Seedling establishment of *Lupinus sulphureus* ssp. *kincaidii* was relatively strong at Isabelle. Neither weeding plots nor scarifying seeds had a significant effect on the number of lupines observed in the plots in 2000-2004 (Table 10). In 2003 and 2004, distinguishing individual plants in some plots had become difficult, thus the total number of lupine leaves per plot was compared among treatments and no significant effects were observed (0.31<*P*<0.93). Seed scarification had a weakly positive effect on the number of leaves per plant in 2003 (in plots with scarified seeds: 94.37±2.44 leaves per plant; plots with unscarified seeds: 50.44±2.52; *P*=0.08). A weak interaction effect of the soil and seed treatments was observed on the number of inflorescences per plant in 2002 (in weeded plots with scarified seeds: 0.53±1.92 inflorescences per plant; weeded plots with unscarified seeds: 2.02±1.99; unweeded, scarified: 1.32±1.99; unweeded, unscarified: 0.46±2.07; *P*=0.07). No other significant effects on measurement data were observed (0.26<*P*<0.95).

Overall, in 2001, the mean maximum width of the lupine plants was 20.35 cm, perpendicular width was 15.55 cm, number of leaves per plant was 28.30, number of inflorescences per plant was 0.07, and 1 Fender's blue butterfly egg was found. In 2002, mean maximum width was 33.93 cm, perpendicular width was 26.03 cm, number of leaves was 72.30, number of inflorescences was 2.73, and 2 butterfly eggs were found. In 2003, mean maximum width was 39.57 cm, perpendicular width was 32.66 cm, number of leaves was 106.33, number of inflorescences was 3.01, and no butterfly egg data were taken. In 2004, mean maximum width was 20.16 cm, perpendicular width was 15.38 cm, number of leaves was 24.58, number of inflorescences was 0.16, and 16 butterfly eggs were found. (Note: The decrease in average plant size from 2003 to 2004 is partially a result of adding data from the 12 plots seeded in 2003. The 2004 means of the data from the original 10 plots are: maximum width: 26.62 cm, perpendicular width: 19.68 cm, number of leaves: 40.92, and number of inflorescences: 0.44.)

Table 10. Mean percent establishment of *Lupinus sulphureus* ssp. *kincaidii* plants (with 95% confidence intervals) observed in 2000-2004 in weeded and undisturbed plots at Isabelle seeded with both scarified and unscarified seeds. P-values are from two-way ANOVA; n=9 for scarified and 10 for unscarified seed treatments. Seeds per plot=50.

Year	Weeded, scarified	Weeded, not scarified	Not weeded, scarified	Not weeded, not scarified	P-value		
					Soil treatment	Seed treatment	Interac-tion
2000	21.60% (9.62-33.58)	21.60% (9.62-33.58)	30.40% (18.42-42.38)	29.20% (17.22-41.18)	0.19	0.92	0.92
2001	10.40% (3.03-17.77)	11.20% (3.83-18.57)	16.80% (9.43-24.17)	11.20% (3.83-18.57)	0.41	0.53	0.41
2002	6.00% (0.39-11.61)	7.20% (1.59-12.81)	11.20% (5.59-16.81)	9.20% (3.59-14.81)	0.23	0.89	0.58
2003	4.13% (0.69-7.57)	6.52% (3.17-9.87)	5.33% (1.89-8.77)	6.27% (2.92-9.62)	0.78	0.41	0.70

2004	3.52% (-0.02-7.06)	5.05% (1.51-8.58)	3.83% (0.29-7.36)	6.08% (2.54-9.62)	0.74	0.33	0.89

Coble – *Lupinus*
Seeding at Coble produced fewer plants per plot on average than at Isabelle. The weeded plots had significantly fewer seedlings in 2002-2004 and there was an interaction effect of the soil and seed treatments in 2004 (Table 11). In 2004, distinguishing individual plants in some plots had become difficult, thus the total number of lupine leaves per plot was compared among treatments and similar results were observed. The number of lupine leaves per plot was significantly greater in unweeded plots (P=0.0001), with a significant interaction between treatments (P=0.02). The number of leaves per plot (±95% confidence intervals) was: 2.26±2.23 in weeded plots with scarified seeds, 0.51±2.23 in weeded plots with unscarified seeds, 5.40±1.80 in unweeded plots with scarified seeds, and 15.12±1.81 in unweeded plots with unscarified seeds.

Table 11. Mean percent establishment of *Lupinus sulphureus* ssp. *kincaidii* plants (with 95% confidence intervals) observed in 2002-2004 in weeded and undisturbed plots at Coble seeded with scarified and unscarified seeds. P-values are from two-way ANOVA; n=20 for soil treatments and 30 for seed treatments. Seeds per plot=50. (*denotes significance at the 0.05 level, **denotes significance at the 0.01 level)

Year	Weeded, scarified	Weeded, not scarified	Not weeded, scarified	Not weeded, Not scarified	P-value		
					Soil treatment	Seed treatment	Interaction
2002**	3.19% (-0.03-6.40)	1.97% (-1.25-5.19)	9.97% (6.75-13.19)	5.67% (2.46-8.89)	0.003	0.14	0.78
2003**	1.67% (-1.71-5.04)	1.24% (-2.13-4.62)	5.49% (2.58-8.41)	11.08% (8.16-13.99)	0.00001	0.41	0.14
2004**	1.11% (-2.12-4.35)	0.38% (-2.85-3.61)	2.84% (0.02-5.67)	6.00% (3.18-8.82)	0.00003	0.72	0.04

Beaver Run – *Aster*
The restored area at Beaver Run appeared better suited to seeding establishment of *Aster curtus*

and no effect of weeding was apparent, but establishment was too infrequent for most statistical comparisons. In the undisturbed plots in the restored area of the prairie, a total of 6 plants were observed in 2000, 4 in 2001, 6 in 2002, 4 in 2003, and 6 in 2004. In the weeded plots in the restored area, a total of 6 plants were observed in 2000, 6 in 2001, 8 in 2002, 5 in 2003, and 6 in 2004 plants. Only one seedling was observed in 2000-2002 in the plots located in the undisturbed area of the prairie. During the summer of 2002, the undisturbed area was mowed and the plots located there can no longer be used in this study (and were difficult or impossible to find). In 2001, overall mean maximum width of the plants was 5.88 cm, perpendicular width was 3.43 cm, height was 11.10 cm, and number of capitula per plant was 2.00. In 2002, mean maximum width was 6.54 cm, perpendicular width was 4.71 cm, height was 8.21, number of stems per plant was 3.67, and number of capitula was 3.42. In 2003, mean maximum width was 10.75 cm, perpendicular width was 5.03 cm, height was 11.06 cm, number of stems was 6.00, and number of capitula was 0.33. In 2004, mean maximum width was 19.28 cm, perpendicular width was 10.00 cm, height was 12.94 cm, number of stems was 7.19, and number of capitula was 6.14.

Transplanting

Greenhill Road, 20x30 m grid – *Aster, Erigeron, Horkelia* and *Lomatium*

Transplant survival in the 20x30 m grid at Greenhill Road was affected by several factors, which varied by species in significance and type of effect (Table 12). Competition and topographic position were random factors with a weak correlation (R^2=0.35)–areas with higher competition, or vegetative cover, were often in high topographic positions, or outside of vernal pools.

Two separate logistic regression analyses of *Aster curtus* transplant survival were necessary as transplants from Balboa were only planted in autumn, thus an analysis on all autumn transplants together was performed first and then an additional analysis was performed on transplants from Greenhill. Fertilizer had a negative effect on survival of transplants planted in autumn to 2003 (*P*=0.04) and 2004 (*P*=0.09), with odds of survival to 2004 for unfertilized plants up to 9.9 times greater than for fertilized plants. Though overall survival was greater for transplants planted in autumn than those planted in spring (Figure 3c), planting season only significantly affected survival to 2003 of transplants from Greenhill (*P*=0.04). Competition had a weakly positive effect on survival to 2003 of transplants from Greenhill (*P*=0.05). Transplant survival was significantly greater in high topographic positions than in low positions–survival of transplants to 2003 and 2004 from Greenhill (*P*=0.04 in both years) and survival of autumn transplants to 2003 (*P*=0.01), with odds of survival to 2004 up to 5.01 times greater for each unit change in position. Overall, 37% of transplants planted in autumn without fertilizer survived to 2004. Among unfertilized autumn transplants planted outside of vernal pools with high competition (≥50% cover at time of planting), 42% survived to 2004. Among transplants planted in spring with fertilizer, 13% survived to 2004; none of the three fertilized spring transplants planted within vernal pools survived to 2004.

Fertilizer had a significant negative effect on survival of *Erigeron decumbens* transplants to both 2003 (*P*=0.002) and 2004 (*P*=0.009). Planting in spring significantly increased odds of survival to both 2003 (*P*=0.0003) and 2004 (*P*=0.0001). Topographic position had a weak effect on transplant survival to 2003 (*P*=0.07), with transplants in high positions having greater survival than those in low positions. Overall, 48% of transplants planted in spring without fertilizer survived to 2004. Among unfertilized spring transplants planted outside of vernal pools, 55% survived to 2004. Only one transplant planted in autumn with fertilizer survived to 2004, a survival rate of 3%, and none of the fertilized autumn transplants were planted within vernal pools.

Fertilizer had a significant negative effect on survival of *Horkelia congesta* transplants to 2004 (*P*=0.004), with odds of survival up to 9.3 times higher for unfertilized transplants than fertilized. Planting in spring significantly increased odds of survival to both 2003 and 2004 (*P*<0.0001 in both years), with odds of survival to 2004 up to 25 times greater for spring transplants than autumn. Seed source had a weak effect on survival to 2003, with more transplants from Fisher Butte surviving than from Greenhill (*P*=0.05). Competition had a significant positive effect on transplant survival to 2004 (*P*=0.008), with odds of survival up to

1.75 times greater for every 10% increase in percent cover of other vegetation. Transplant survival to 2003 in high topographic positions was significantly greater than in low positions (*P*=0.02). Overall, 70% of transplants planted in spring without fertilizer survived to 2004. Among unfertilized spring transplants in locations of high competition (≥50% cover at time of planting), 83% survived to 2004 (which equals the survival of unfertilized spring transplants planted outside of vernal pools). Within this category, transplants from Fisher Butte had a 79% survival rate and those from Greenhill had a 73% survival rate. Among transplants planted in autumn with fertilizer, 18% survived to 2004; none of the fertilized autumn transplants planted in locations of low competition (≤50% cover at time of planting), including the single transplant planted within a vernal pool, survived to 2004.

Fertilization alone had no effect on survival of *Lomatium bradshawii* transplants, though it interacted significantly with planting season in both 2003 (*P*=0.01) and 2004 (*P*=0.02). Planting in autumn significantly increased odds of survival to both 2003 (*P*=0.006) and 2004 (*P*=0.04), with fertilizer positively affecting survival to 2003 of autumn transplants and negatively affecting survival to both 2003 and 2004 of spring transplants. Odds of spring transplants surviving to 2004 were up to 7 times greater for unfertilized transplants than fertilized. Competition had a significant negative effect on transplant survival to both 2003 (*P*=0.001) and 2004 (*P*<0.0001), with odds of survival to 2004 up to 1.8 times greater for every 10% decrease in cover of other vegetation. Transplants in low topographic positions had significantly greater survival to 2003 (*P*=0.0007) and 2004 (*P*=0.04) than those in high positions, with odds of survival up to 2.15 times greater with every unit change in position. Overall, 37% of transplants planted in autumn , and 43% of autumn transplants with fertilizer , survived to 2004. Among autumn transplants planted within vernal pools with low competition (≤30% cover at time of planting), 75% survived to 2004. Among transplants planted in spring without fertilizer, 32% survived to 2004; among unfertilized spring transplants planted within vernal pools with low competition (≤30% cover at time of planting), 40% survived to 2004. Among transplants planted in spring with fertilizer, 15% survived to 2004; among fertilized spring transplants planted outside of vernal pools with high competition (≥50% cover at time of planting), 6% survived to 2004.

Sample size of transplant flowering response was small and data could not be analyzed for the effects of all factors in the study. Effects of a few variables were observed on each species (Table 13). Fertilizer had a weakly negative effect on 2004 flowering response of *A. curtus* transplants from Greenhill (*P*=0.08) but no effect on transplants from Balboa (*P*=1). Fertilizer also had a weakly negative effect on spring transplants (*P*=0.1) but not autumn transplants (*P*=1) in 2004. Transplants planted in spring were more likely to flower in 2004 than those planted in autumn. All three surviving unfertilized spring transplants (or 19% of transplants planted) were reproductive in 2004, while only 20% of fertilized autumn transplants (or 3% of transplants planted) were reproductive.

Seed source and competition both weakly affected flowering response in 2003 of *E. decumbens*, with more transplants from Oxbow and Fisher Butte with low competition being reproductive than transplants from Greenhill with high competition. Planting season and Greenhill transplant data could not be analyzed in 2004 due to low survival rates. Fertilizer had an apparently positive effect on flowering response of transplants from Oxbow and Fisher Butte in 2004 (all fertilized transplants were reproductive), though this was not statistically significant (P=0.24 and P=0.54, respectively). All surviving transplants (or 46% of transplants planted) from Oxbow and 78% of surviving transplants (or 30% of transplants planted) from Fisher Butte with low competition (≤30% cover at time of planting) were reproductive in 2003. In 2004, 60% of surviving transplants (or 31% of transplants planted) from Oxbow and 57% of surviving transplants (or 19% of transplants planted) from Fisher Butte were reproductive. Half of the surviving transplants (or 8% of transplants planted) from Greenhill with high competition (≥50% cover at time of planting) were reproductive in 2003 and all survivors (or 8% of transplants planted) were reproductive in 2004. Most surviving transplants (76%) were reproductive in 2004, including all of those planted with fertilizer, in autumn, or from Greenhill, factors with lower survival rates than their counterparts.

Planting in spring had a weakly positive effect on flowering response of *H. congesta* transplants in 2004 (P=0.09). The probability of a surviving transplant planted in spring to reproduce in 2004 was 85%, while the probability was 59% for one planted in autumn. Seed source also had a weak effect in 2004 (P=0.1), with transplants from Greenhill more likely to be reproductive than transplants from Fisher Butte. Overall, 94% of spring transplants from Greenhill and 54% of autumn transplants from Fisher Butte were reproductive in 2004.

Flowering response in 2003 of *L. bradshawii* transplants was weakly affected by fertilizer treatment and significantly affected by topographic position, with more fertilized transplants in low positions being reproductive than unfertilized in high positions. Among surviving *L. bradshawii* transplants that were fertilized and planted within vernal pools, 83% were reproductive in both 2003 and 2004 (or 31% of transplants planted). Among surviving transplants that were not fertilized and planted outside of vernal pools, 24% were reproductive in 2003 and 50% in 2004 (or 8% and 15%, respectively, of transplants planted).

Table 12. Effects of fertilizer, planting season, seed source, competition, and topographic position on survival of *Aster curtus*, *Erigeron decumbens*, *Horkelia congesta*, and *Lomatium bradshawii* transplants in the 20x30 m grid at Greenhill Road in 2003 and 2004. P-values are from logistic regression analysis; n=91 for *A. curtus*, 187 for *E. decumbens*, 136 for *H. congesta*, and 207 for *L. bradshawii*. (*denotes significance at the 0.05 level, **denotes significance at the 0.01 level, †denotes weak effect (0.05<*P*<0.1), – indicates no effect)

Species	Fertilizer		Planting season		Seed source		Competition		Topographic position	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Aster curtus	Negative*	Negative†	Fall*	–	–	–	Positive†	–	High*	High*
Erigeron decumbens	Negative**	Negative**	Spring**	Spring**	–	–	–	–	High†	–
Horkelia congesta	–	Negative**	Spring**	Spring**	Fisher Butte†	–	–	Positive**	High*	–
Lomatium bradshawii	Positive (fall transplants only**)	Negative (spring transplants only*)	Fall** (when fertilized)	Fall*	N/A	N/A	Negative**	Negative**	Low**	Low*

Table 13. Effects of fertilizer, planting season, seed source, competition, and topographic position on flowering response of *Aster curtus, Erigeron decumbens, Horkelia congesta*, and *Lomatium bradshawii* transplants in the 20x30 m grid at Greenhill Road in 2003 and 2004. P-values are from logistic regression analysis; n=91 for *A. curtus*, 187 for *E. decumbens*, 136 for *H. congesta*, and 207 for *L. bradshawii*. (*denotes significance at the 0.05 level,†denotes weak effect (0.05<*P*<0.1), – indicates no effect, blank cells indicate data that could/was not be analyzed)

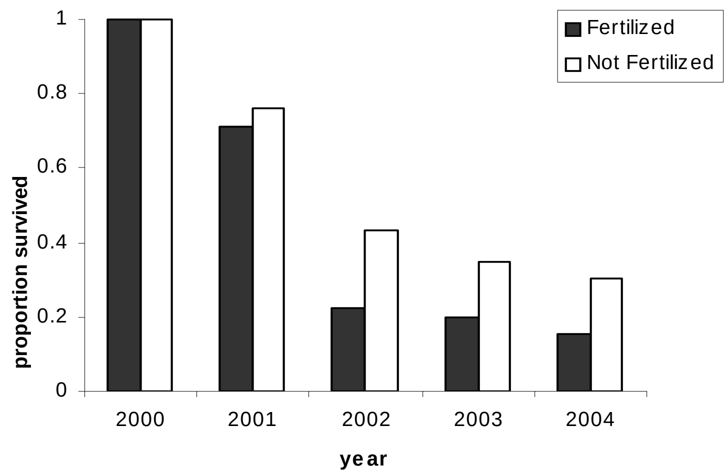
Species	Fertilizer		Planting season		Seed source		Competition	Topographic position
	2003	2004	2003	2004	2003	2004	2003	2003
Aster curtus		Negative†	–	Spring	–	–	–	–
Erigeron decumbens	–	–	–		Oxbow & Fisher Butte†		Negative†	–
Horkelia congesta	–	–	–	Spring†	–	Greenhill†	–	–

Lomatium bradshawii	Positive†	–	–	–	N/A	N/A	–	Low*

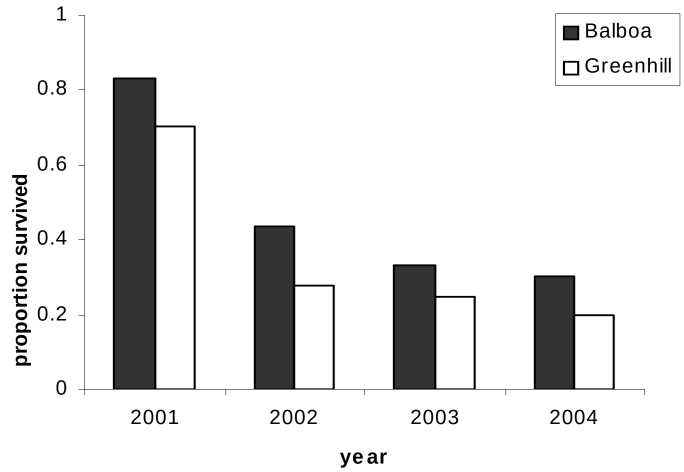
Aster curtus — Survival of *Aster curtus* transplants was not significantly affected by fertilizer, seed source, or planting season in 2001 or 2002 ($0.32<P<0.93$; Figure 3). These factors did not significantly affect flowering response in 2002 ($0.17<P<0.87$) and 2001 data could not be analyzed by logistic regression (Figure 4).

Mean perpendicular width of the transplants from Balboa was significantly greater (8.74±2.23 cm) than those from Greenhill (4.86±2.16 cm) in 2001 ($P=0.004$). The perpendicular width of spring transplants was significantly greater (7.97±2.23 cm) than autumn transplants (5.32±2.16 cm) in 2001 ($P=0.046$). Mean height of the transplants from Balboa was significantly greater (8.80±2.43 cm) than those from Greenhill (4.23±2.30 cm) in 2001 ($P=0.03$). No other significant effects of fertilizer treatment, planting season, or seed source were detected for transplant measurements ($0.17<P<1$).

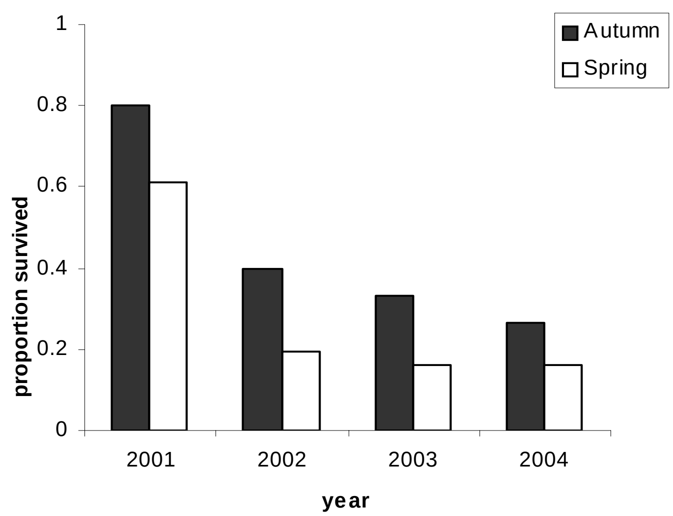
In 2000 (spring transplants only), the mean maximum width of the transplants was 7.11 cm, perpendicular width was 6.10 cm, height was 11.63 cm, and number of capitula per transplant was 1.04. In 2001, mean maximum width was 7.99 cm, perpendicular width was 4.89 cm, height was 4.46 cm, and number of capitula was 0.02. In 2002, mean maximum width was 21.73 cm, perpendicular width was 10.51 cm, height was 14.54 cm, number of stems per transplant was 6.42, and number of capitula was 0.78. In 2003, mean maximum width was 24.17 cm, perpendicular width was 9.33 cm, height was 12.44 cm, number of stems was 6.16, and number of capitula was 1.50. In 2004, mean maximum width was 14.46 cm, perpendicular width was 9.44 cm, height was 6.10 cm, number of stems was 5.75, and number of capitula was 4.84.


Fertilized
Not Fertilized
proportion survived
1
0.8
0.6
0.4
0.2
0
2000
2001
2002
2003
2004
year

(a)

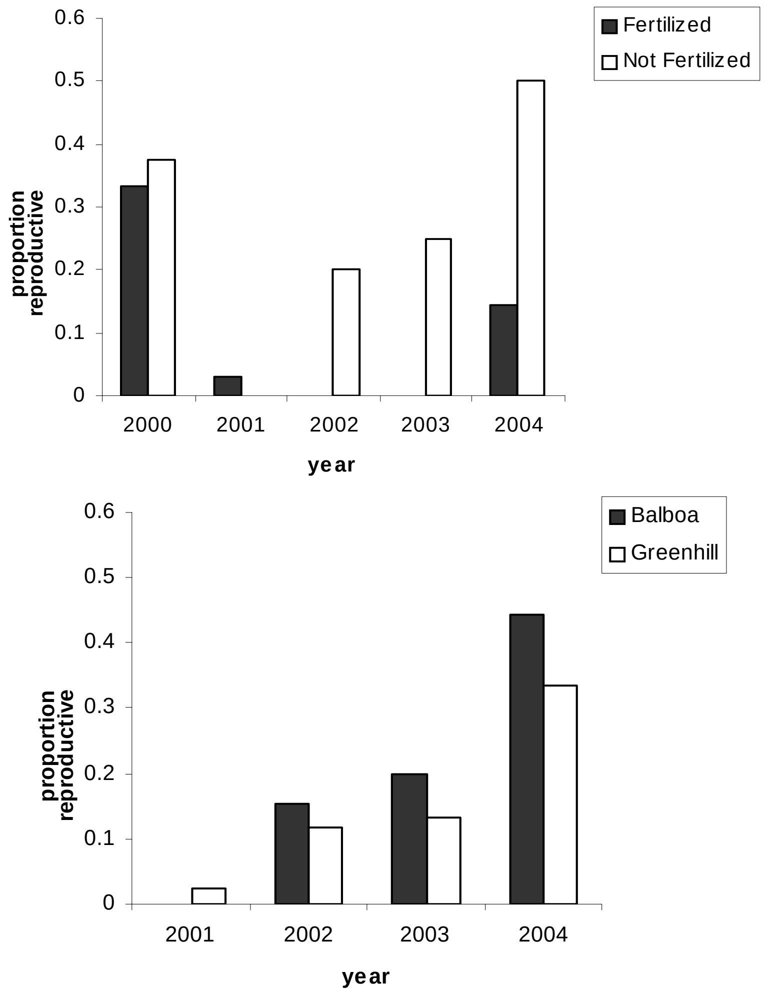

Balboa
Greenhill
proportion survived
1
0.8
0.6
0.4
0.2
0
2001
2002
2003
2004
year

(b)


Autumn
Spring
proportion survived
1
0.8
0.6
0.4
0.2
0
2001
2002
2003
2004
year

(c)

Figure 3. Proportion of *Aster curtus* transplants that survived in the Greenhill 20x30 m grid in 2000-2004 by (a) fertilizer treatment, (b) seed source, and (c) planting season.

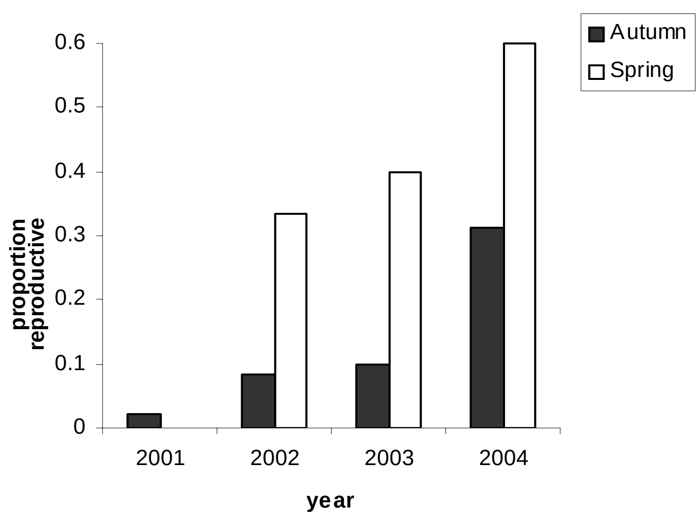


(a)

(b)

(c)

Figure 4. Proportion of *Aster curtus* transplants that were reproductive in the Greenhill 20x30 m grid in 2000-2004 by (a) fertilizer treatment, (b) seed source, and (c) planting season.



Erigeron decumbens — Fertilizer negatively affected survival of *Erigeron decumbens* transplants to 2001 (P=0.001) and 2002 (P=0.001; Figure 5). A significantly greater proportion of transplants planted in spring survived until 2001 (P=0.002) and 2002 (P=0.01). A significant interaction was observed between fertilization treatment and planting season in 2001 (P=0.003) and 2002 (P=0.03) and a weak interaction between seed source and planting season in 2001 (P=0.07). Seed source did not significantly affect survival in 2001 or 2002 ($0.38<P<0.77$). Neither fertilizer nor planting season affected the flowering response of *E. decumbens* transplants in 2001 and 2002 ($0.38<P<0.82$; Figure 6). Seed source did not significantly affect the proportion of transplants that were reproductive in 2001 or 2002 ($0.18<P<0.88$), though there was a weak effect on transplants from Fisher Butte in 2001 (P=0.09). The 2000 data could not be analyzed by logistic regression.

The mean maximum width of the fertilized transplants (13.01±2.06 cm) was significantly greater than the unfertilized transplants (8.72±2.05 cm) in 2000 (P=0.000005). The mean perpendicular width of the fertilized transplants (9.35±2.06 cm) was significantly greater than the unfertilized transplants (5.69±2.06 cm) in 2000 ($P<0.000001$). Seed source had a weak effect on perpendicular width in 2001 (P=0.06), with means of 6.96±2.17 cm for Fisher Butte, 6.43±2.20 cm for Oxbow, and 3.60±2.47 cm for Greenhill. Fertilization treatment also had a weak effect on perpendicular width in 2001 (unfertilized transplants: 6.55±2.16 cm; fertilized: 4.51±2.19 cm; P=0.06). The mean height of the fertilized transplants (9.60±2.13 cm) was significantly greater than the unfertilized transplants (4.83±2.16 cm) in 2000 (P=0.003). Planting season had a weak effect on transplant height in 2004 (autumn transplants: 39.63±6.15 cm; spring: 30.45±2.11 cm; P=0.09). No other significant effects were observed ($0.35<P<1$).

In 2001, the mean maximum width of the transplants was 10.07 cm, perpendicular width was 5.44 cm, and height was 9.74 cm. In 2002, mean maximum width was 11.37 cm, perpendicular width was 7.68 cm, and height was 13.86 cm. In 2003, mean maximum width was 14.51 cm, perpendicular width was 9.78 cm, and height was 19.33 cm. In 2004, mean maximum width was 35.15 cm, perpendicular width was 11.82 cm, and height was 35.04 cm. The mean number of inflorescences per transplant was 0.42 in 2000, 0.50 in 2001, 2.52 in 2002, 8.38 in 2003, and 11.66 in 2004.

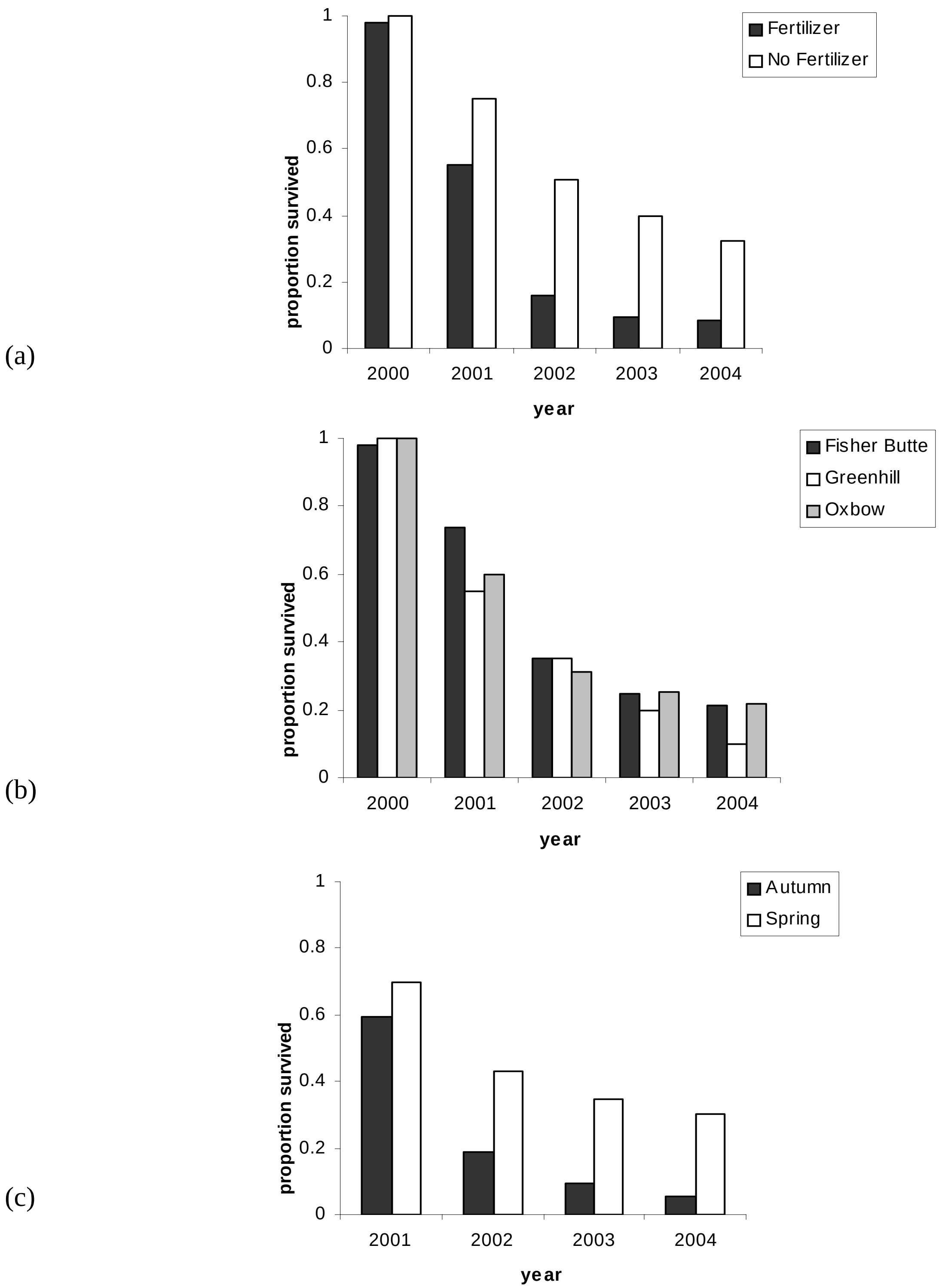


Figure 5. Proportion of *Erigeron decumbens* transplants that survived in the Greenhill 20x30 m grid in 2000-2004 by (a) fertilizer treatment, (b) seed source, and (c) planting season.

(a)

(b)

(c)

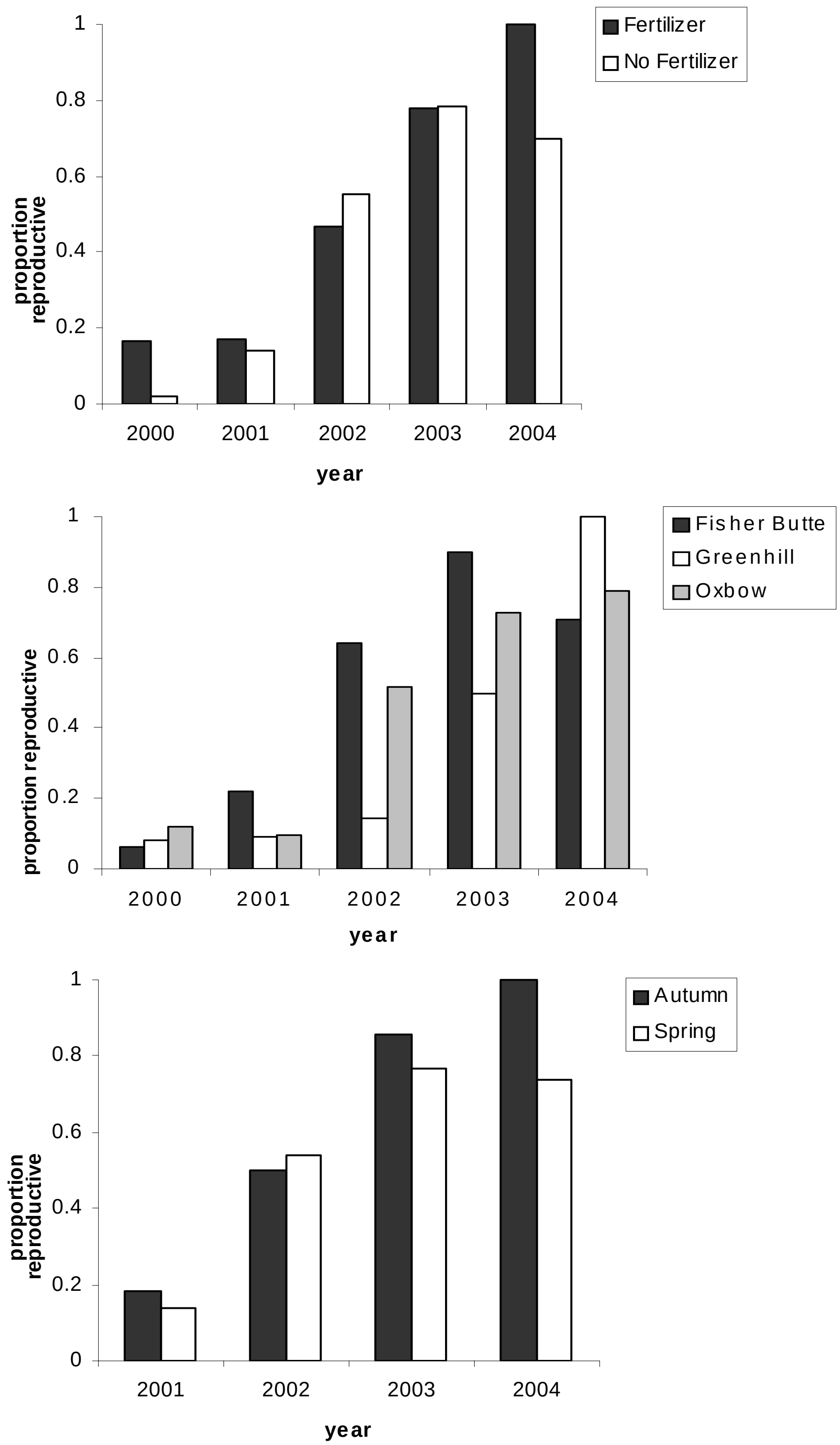


Figure 6. Proportion of *Erigeron decumbens* transplants that were reproductive in the Greenhill 20x30 m grid in 2000-2004 by (a) fertilizer treatment, (b) seed source, and (c) planting season.

Horkelia congesta — Survival of *Horkelia congesta* transplants to 2002 was significantly greater for transplants planted in spring (*P*=0.02; Figure 7). No other significant effects were observed on survival or proportion of transplants that were reproductive in 2001 and 2002 (0.11<*P*<1) and the 2000 data could not be analyzed by logistic regression. Figure 8 shows the proportion of transplants in each treatment that were reproductive.

The mean maximum width of the fertilized transplants (23.41±1.53 cm) was significantly greater than the unfertilized (19.30±1.54 cm) in 2001 (*P*=0.0004). The effects of seed source (*P*=0.59) and planting season (*P*=0.41) were not significant, but there was a significant interaction between the two variables (*P*=0.04). The mean perpendicular width of fertilized transplants (19.28±1.44 cm) was significantly greater than unfertilized transplants (16.98±1.45 cm) in 2001 (*P*=0.03). A significant interaction effect on transplant height was observed in 2001 between seed source and planting season (*P*=0.02), but the variables did not alone significantly affect height (*P*=0.16 and 0.34, respectively). Fertilization had a weak effect on maximum width in 2003 (fertilized transplants: 19.98±2.08 cm; unfertilized: 17.01±2.08 cm; *P*=0.08). The mean maximum width of transplants planted in spring (22.76±2.08 cm) was significantly greater than those planted in autumn (19.24±2.08 cm) in 2004 (*P*=0.049). Seed source had a weak effect on mean perpendicular width in 2004 (Fisher Butte: 17.15±2.07 cm, Greenhill: 14.74±2.07 cm, *P*=0.05). No other significant effects were observed (0.12<*P*<0.94).

In 2000, the mean maximum width of the transplants was 12.96 cm, perpendicular width was 10.32 cm, height was 11.16 cm, and number of inflorescences was 0.87. In 2001, mean maximum width was 21.35 cm, perpendicular width was 18.13 cm, height was 20.95 cm, and number of inflorescences was 1.57. In 2002, mean maximum width was 20.83 cm, perpendicular width was 17.32 cm, height was 29.22 cm, and number of inflorescences was 2.25. In 2003, mean maximum width was 18.22 cm, perpendicular width was 14.28 cm, height was 29.50 cm, number of inflorescences was 2.69, and 49 seedlings were observed near the transplants. In 2004, mean maximum width was 20.93 cm, perpendicular width was 15.90 cm, height was 33.36 cm, number of inflorescences was 3.47, and 41 seedlings were observed.

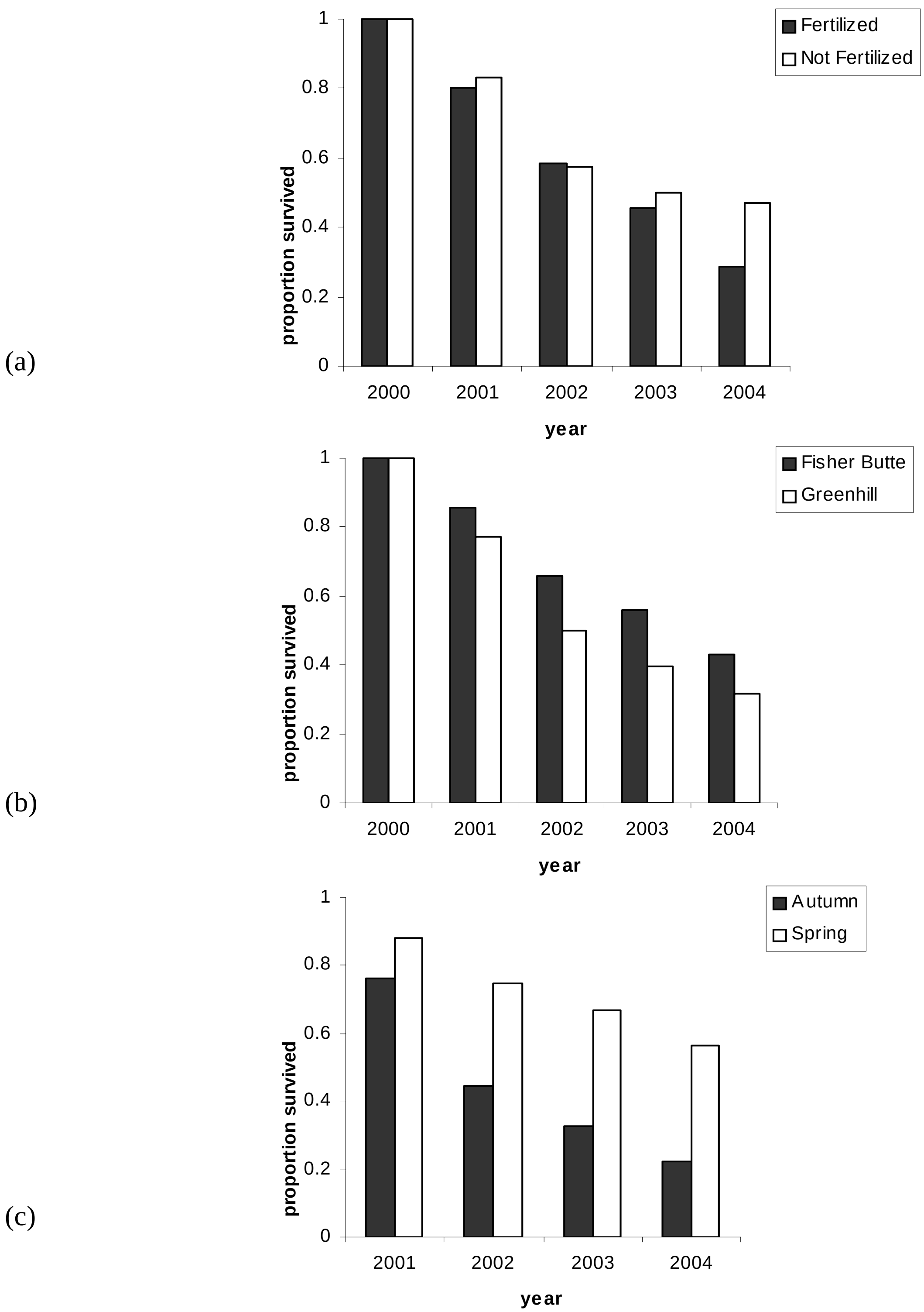
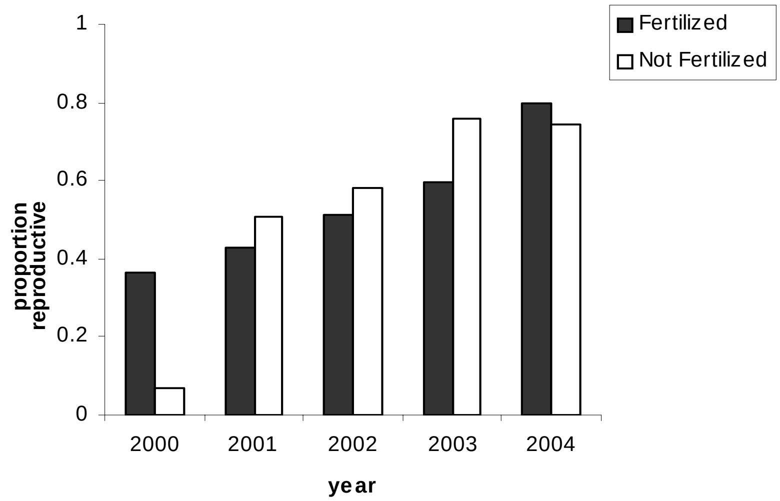
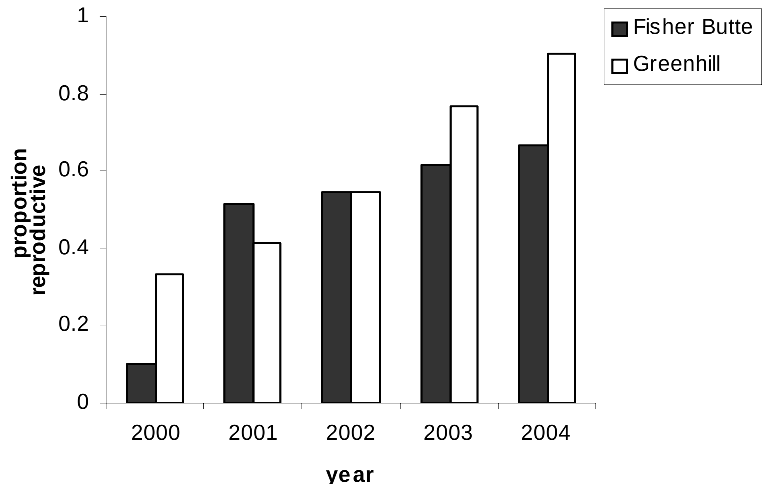


Figure 7. Proportion of *Horkelia congesta* transplants that survived in the Greenhill 20x30 m grid in 2000-2004 by (a) fertilizer treatment, (b) seed source, and (c) planting season.

(a)



(b)



(c)

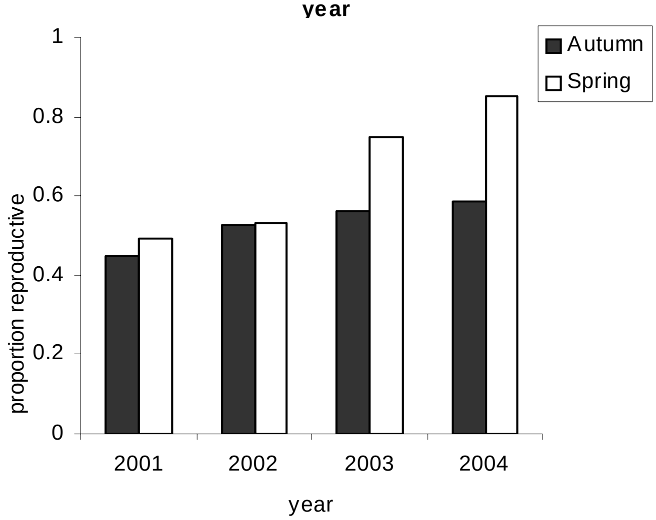


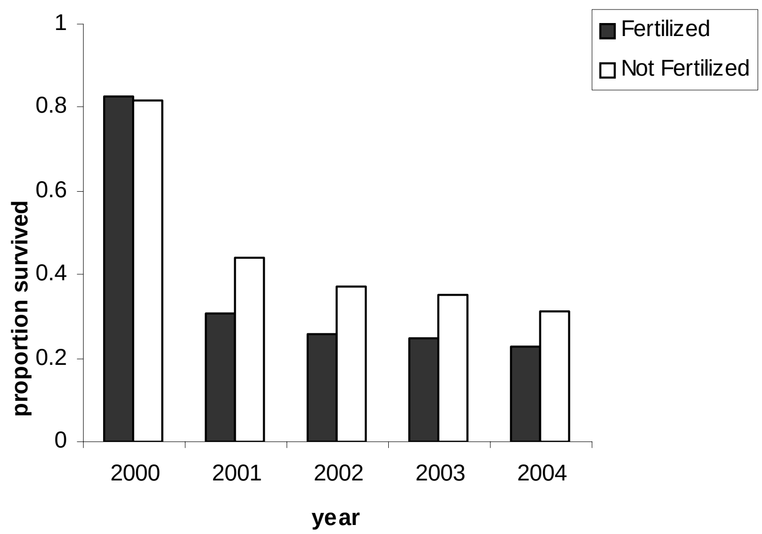
Figure 8. Proportion of *Horkelia congesta* transplants that were reproductive in the Greenhill 20x30 m grid in 2000-2004 by (a) fertilizer treatment, (b) seed source, and (c) planting season.

Lomatium bradshawii — Survival of unfertilized *Lomatium bradshawii* transplants was significantly greater to 2001 (*P*=0.03) and 2002 (*P*=0.01) than fertilized transplants (Figure 9). The interaction between fertilizer treatment and planting season also showed a significant effect in 2002 (*P*=0.02). No other effects were significant (0.11<*P*<0.89). The 2001 and 2002 flowering response data could not be analyzed by logistic regression. Figure 10 shows the proportion of transplants in each treatment that were reproductive.

Much of the measurement data could not be analyzed by ANOVA. Transplant size in 2000 and height in 2001 did not significantly differ by fertilizer treatment or planting season (0.21<*P*<0.80). In 2000, the mean maximum width of the transplants was 2.34 cm, perpendicular width was 1.66 cm, and no inflorescences were observed. In 2001, mean maximum width was 6.60 cm, perpendicular width was 4.22 cm, height was 12.69 cm, and number of inflorescences per transplant was 0.13. Measurement data was not taken in following years, but a summary of the number of transplants observed in each growth stage is presented in Table 14.

Table 14. Number of *Lomatium bradshawii* transplants in each of six growth stages at the Greenhill Road 20x30 m grid in 2001-2004. Growth stage was not recorded for all plants observed in each year.

Year	Growth stage						Total number of plants	
	Seedling	V1-V2	V3+	R1	R2	R3	Vege-tative	Repro-ductive
2001	0	26	30	0	0	0	56	0
2002	0	7	51	2	0	0	58	2
2003	0	8	37	9	7	1	45	17
2004	0	0	29	15	9	3	29	27

(a) 

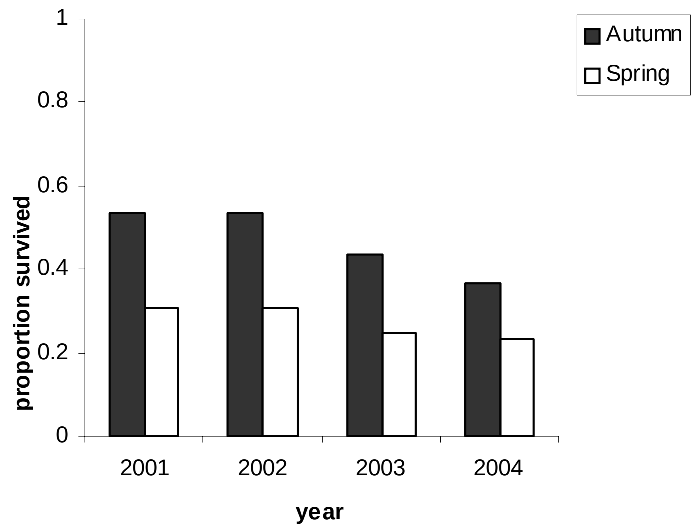
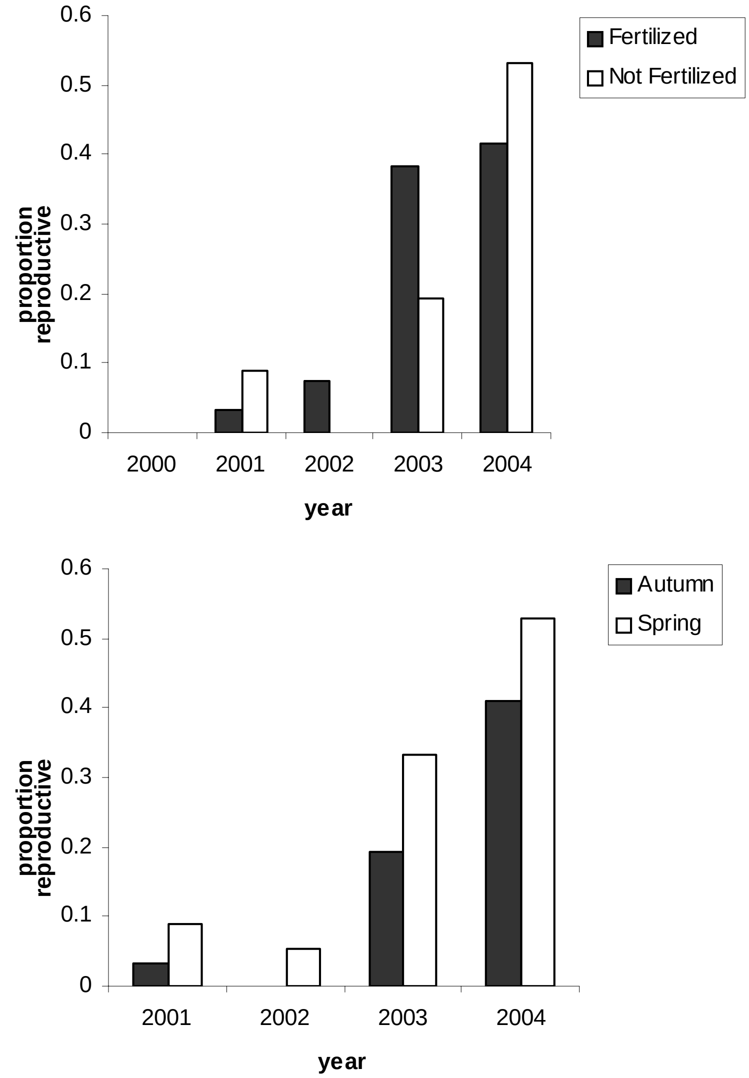
(b) 

Figure 9. Proportion of *Lomatium bradshawii* transplants that survived in the Greenhill 20x30 m grid in 2000-2004 by (a) fertilizer treatment and (b) planting season.

(a)



(b)

Figure 10. Proportion of *Lomatium bradshawii* transplants that were reproductive in the Greenhill 20x30 m grid in 2000-2004 by (a) fertilizer treatment and (b) planting season.

Greenhill Road – *Erigeron* and *Horkelia* arrays

Survival and flowering response of *Erigeron decumbens* transplants in the arrays were not affected by seed source in 2001-2004 (0.13<*P*<0.77). The proportion of transplants from each seed source that survived and were reproductive is shown in Figure 11.

In 2001, the mean maximum width of the transplants was 18.93±3.54 cm, perpendicular width was 15.35±3.04 cm, height was 17.78±3.21 cm, and number of inflorescences per transplant was 12.55±4.84. In 2002, mean maximum width was 12.78±1.67 cm, perpendicular width was 9.60±1.33 cm, height was 12.37±1.44 cm, and there were no inflorescences. In 2003, mean maximum width was 11.76±2.35 cm, perpendicular width was 7.95±1.79 cm, height was 19.00±3.54 cm, and number of inflorescences was 6.85±3.93. In 2004, mean maximum width was 17.80±3.74 cm, perpendicular width was 11.20±1.57 cm, height was 20.70±4.95 cm, number of inflorescences was 8.00±7.19, and 1 seedling was observed near the transplants.

(a) (b)

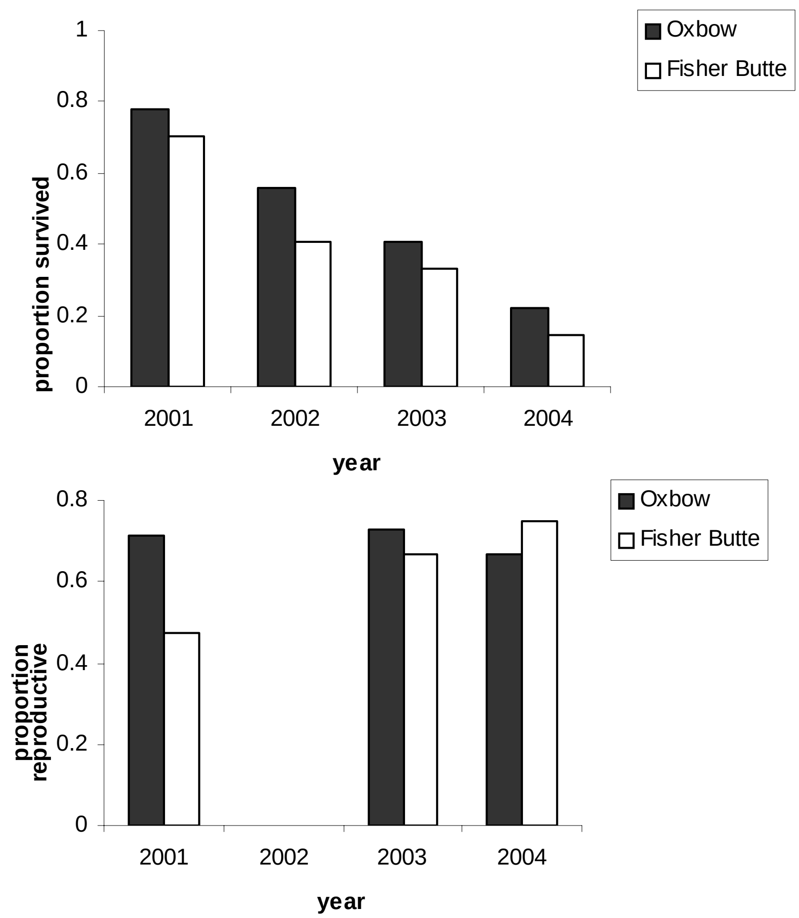
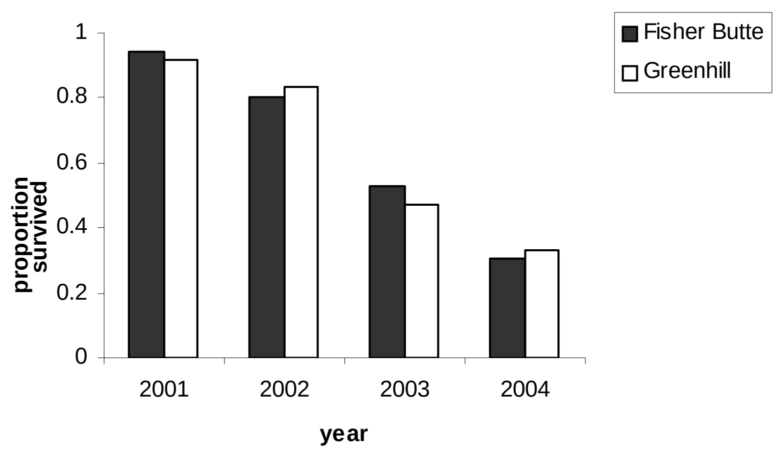


Figure 11. Proportion of *Erigeron decumbens* transplants that (a) survived and (b) were reproductive in Greenhill Road arrays in 2001-2004.

Survival and flowering response of *Horkelia congesta* transplants in the arrays were not affected by seed source (0.11<*P*<0.80). The proportion of transplants from each seed source that survived and were reproductive is shown in Figure 12.

In 2001, the mean maximum width of the transplants was 19.09±1.67 cm, perpendicular width was 15.37±1.14 cm, vegetative height was 11.64±0.60 cm, flowering height was 36.44±2.99 cm, and number of inflorescences per transplant was 0.85±0.43. In 2002, mean maximum width was 15.20±1.18 cm, perpendicular width was 12.41±1.18 cm, vegetative height was 11.95±0.82 cm, and there were no inflorescences. In 2003, mean maximum width was 15.74±1.94 cm, perpendicular width was 12.35±1.58 cm, vegetative height was 14.29±1.22 cm, flowering height was 29.92±5.30 cm, number of inflorescences was 1.09±0.74, and 1 seedling was observed near the transplants. In 2004, mean maximum width was 20.61±2.10 cm, perpendicular width was 16.22±1.76 cm, height was 33.26±7.63 cm, number of inflorescences was 2.43±0.86, and 1 seedling was observed.

(a)



(b)

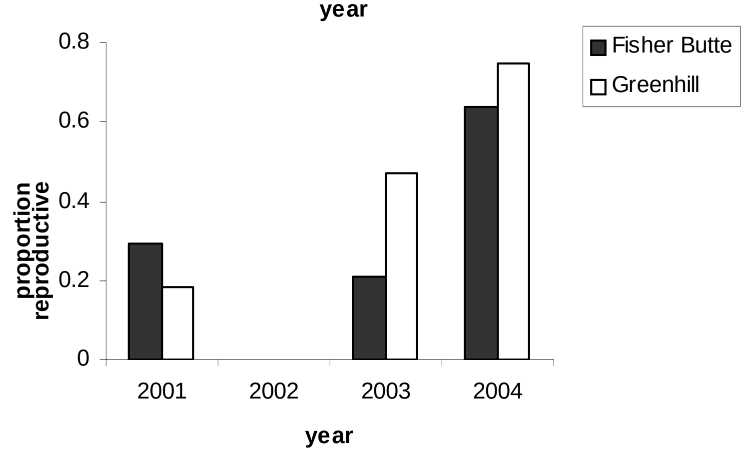


Figure 12. Proportion of *Horkelia congesta* transplants that (a) survived and (b) were reproductive in Greenhill Road arrays in 2001-2004.

Balboa & Rosy – *Lomatium*

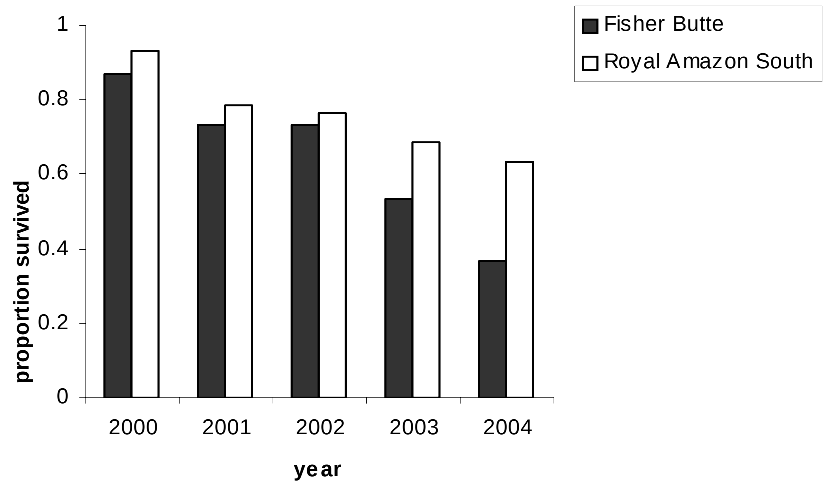
Survival of *Lomatium bradshawii* transplants was not affected by seed source, planting site, or soil amendments ($0.12<P<0.97$; Figure 13). Flowering response data could not be analyzed by logistic regression, but the proportion of transplants in each treatment that were reproductive is presented in Figure 14.

A summary of the number of transplants observed in each growth stage is presented in Table 15. Grazing was observed on a few transplants. In 2000, one transplant at Rosy showed signs of grazing. In 2001, two V2s and two V3s at Balboa were grazed. In 2002, two V2s, three V3s, one R1, and one R2 at Rosy and three V2s and two V3s at Balboa were grazed. In 2003, three V3s and one R1 at Rosy and nine V3s, one R1, and one R2 at Balboa were grazed. Grazing was not noted in 2004.

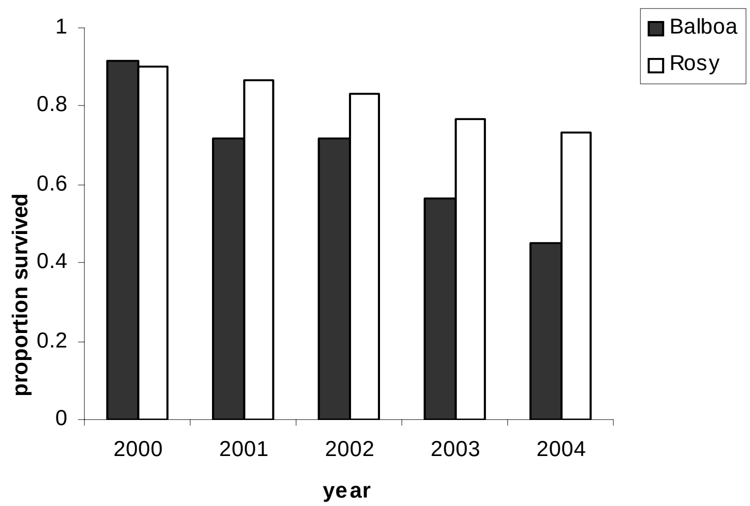
Table 15. Number of *Lomatium bradshawii* transplants in each of six growth stages at the Rosy and Balboa planting sites in 2001-2004. Growth stage was not recorded for all plants observed in each year.

Year	Growth stage						Total number of plants	
	Seedling	V1-V2	V3+	R1	R2	R3	Vegetative	Reproductive
2001	0	8	40	6	1	0	48	7
2002	0	7	46	8	2	0	53	10
2003	0	3	39	8	1	0	42	9
2004	0	4	31	9	5	0	35	14

(a)



(b)



(c)

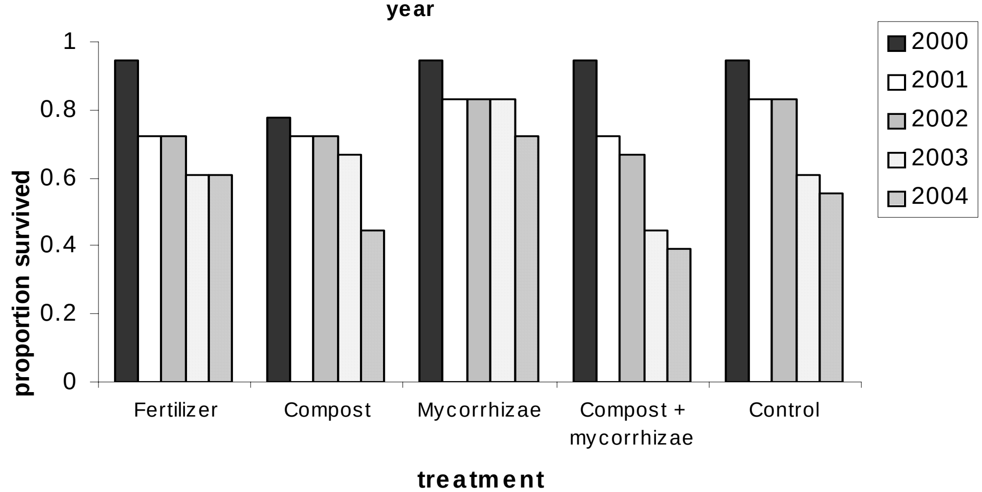


Figure 13.
Proportion of *Lomatium bradshawii* transplants that survived at Rosy and Balboa in 2000-2004 by (a) seed source, (b) planting site, and (c) soil treatment.

(a)

(b)

(c)

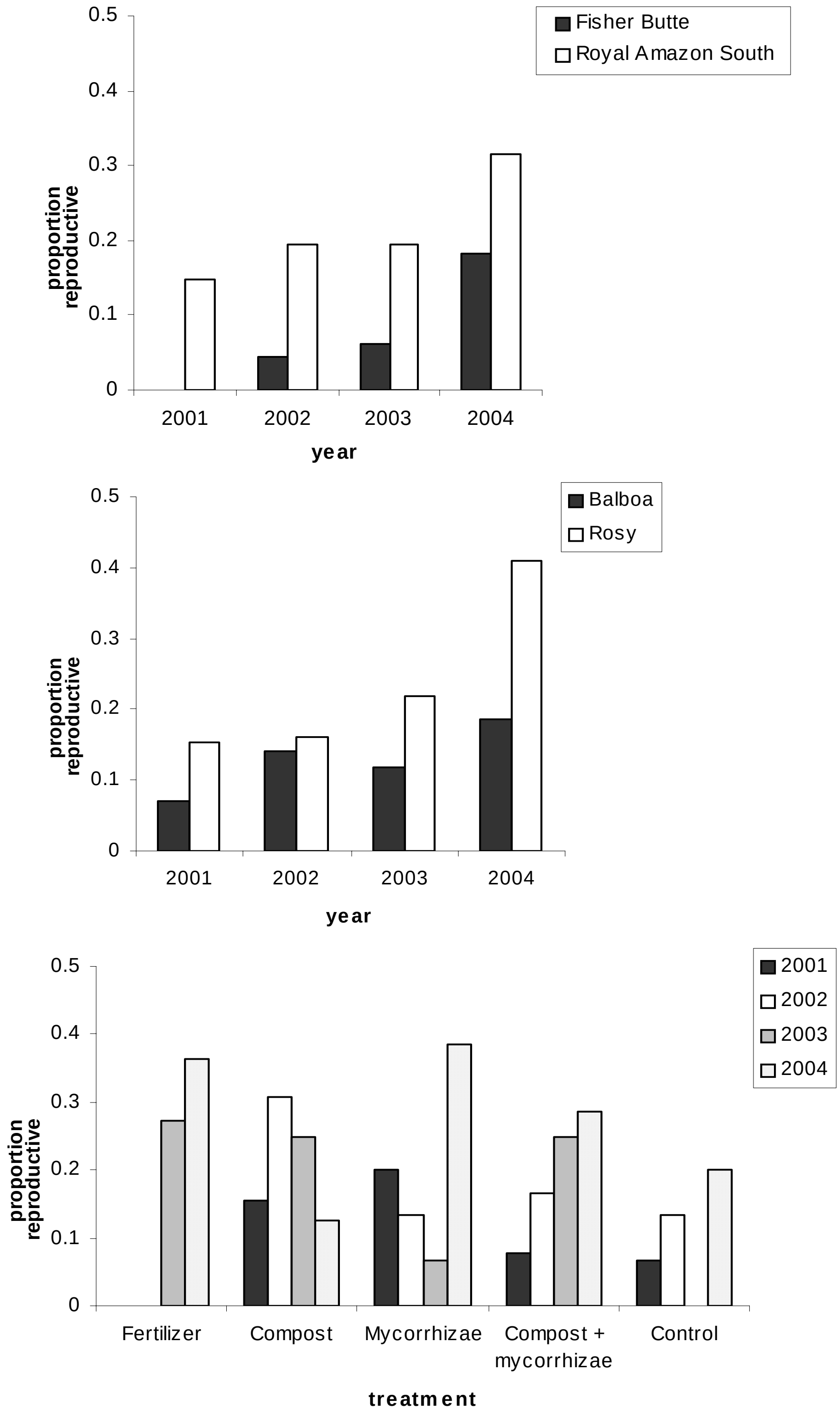


Figure 14. Proportion of *Lomatium bradshawii* transplants that were reproductive at Rosy and Balboa in 2001-2004 by (a) seed source, (b) planting site, and (c) soil treatment.

Balboa, 1135, and Oxbow West – *Lupinus*

In the planting grid at Balboa, 54 plants were observed in May 2000, 9 plants in June 2000, and only 1 plant in May 2001. No plants survived to 2002. In May 2000, mean maximum width of the transplants was 10.57±1.02 cm, perpendicular width was 6.52±0.72 cm, and number of leaves per transplant was 11.74±2.31. In June 2000, mean maximum width was 7.89±2.10 cm, perpendicular width was 4.67±1.39 cm, and number of leaves was 9.11±3.45. In May 2001, the remaining plant was 15 by 13 cm with 7 leaves. In the two other planting patches at Balboa, all 19 plants were observed in May 2000 and 4 were observed in June 2000 and May 2001 following disturbance to the patches by a motorized vehicle. In May 2000, mean maximum width of the transplants was 9.95±1.77 cm, perpendicular width was 6.05±1.19 cm, and number of leaves per transplant was 5.63±1.17. In June 2000, mean maximum width was 5.25±2.58 cm, perpendicular width was 3.50±1.27 cm, and number of leaves was 3.50±2.47. The May 2001 measurements were identical to June 2000.

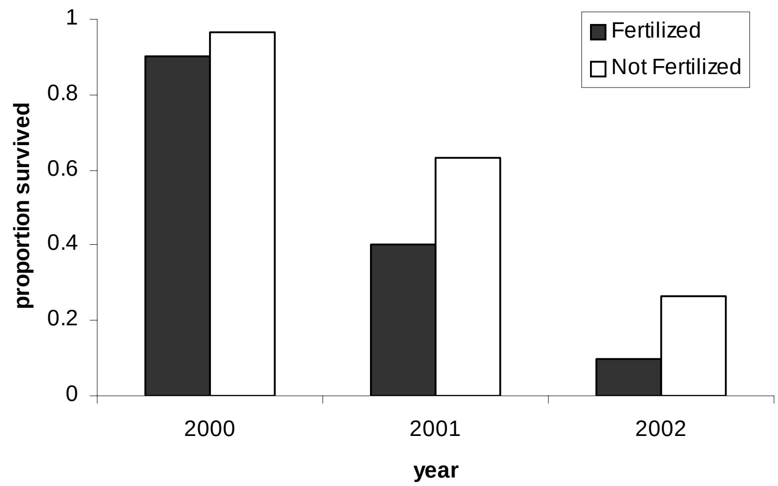
At 1135, 67 transplants were observed in May 2000, 47 in June 2000, and 3 in May 2001. No plants survived to 2002. In May 2000, mean maximum width of the transplants was 13.97±1.64 cm, perpendicular width was 9.36±1.29 cm, and number of leaves per transplant was 8.45±1.26. In June 2000, mean maximum width was 8.83±1.08 cm, perpendicular width was 6.09±0.77 cm, and number of leaves was 10.38±2.13. In May 2001, mean maximum width was 13.33±6.91 cm, perpendicular width was 8.33±1.73 cm, and number of leaves was 17.67±14.15.

At Oxbow West, 10 plants were observed in 2000, 6 in 2001 and 2002, and 4 in 2003 and 2004. In 2000, mean maximum width of the transplants was 8.90±2.52 cm, perpendicular width was 6.60±1.58 cm, and number of leaves per transplant was 10.60±2.95. In 2001, mean maximum width was 15.67±3.02 cm, perpendicular width was 11.33±2.00 cm, and number of leaves was 23.67±8.55. In 2002, mean number of leaves was 21.5±6.23 and number of eggs per transplant was 7.33±5.10. In 2003, mean maximum width was 23.75±5.95 cm, perpendicular width was 17.25±7.04 cm, number of leaves was 32.00±15.33, and number of eggs was 27.00±20.57. In 2004, mean number of leaves was 32.25±36.94 and number of eggs was 63.25±58.17. No inflorescences were observed in 2001-2004.

Greenhill Road – *Lupinus*

Survival of *Lupinus sulphureus* ssp. *kincaidii* transplants at Greenhill Road did not significantly vary by treatment in 2001 (0.15<*P*<0.79) or 2002 (0.37<*P*<1; Figure 15). In 2000, the majority of transplants survived, so survival could not be analyzed by logistic regression. Plant size did not vary significantly by treatment in 2000-2002 (0.16<*P*<0.98). In 2000, transplants averaged 14.22 by 9.98 cm in area with 15.78 leaves. In 2001, they averaged 13.67 by 11.03 cm with 15.31 leaves. In 2002, they averaged 15.94 by 10.60 cm with 15.50 leaves. No plants in the grid survived to 2003. Of the five lupine transplants on the small hill, all survived to 2002 and four survived to 2004.

(a)



(b)

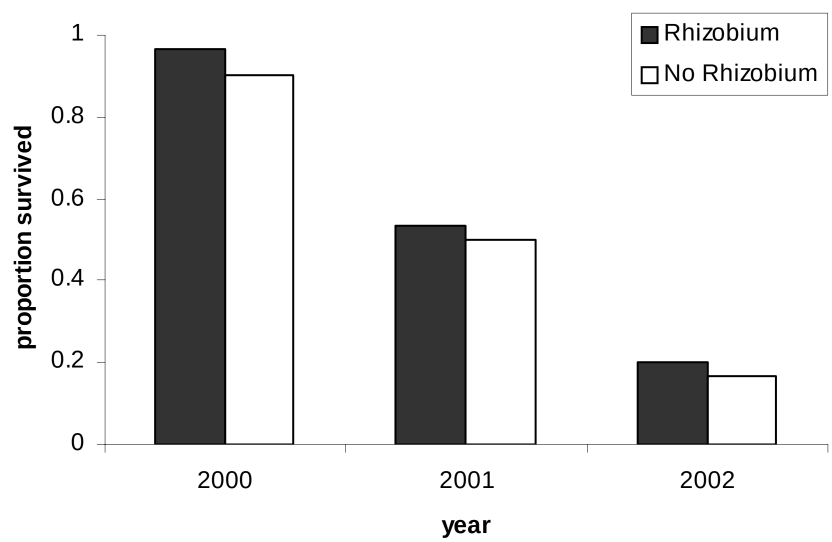


Figure 15. Proportion of transplants of *Lupinus sulphureus* ssp. *kincaidii* that survived at Greenhill Road when (a) fertilized or not and (b) nodulating bacteria was applied or not.

Isabelle – *Lupinus*

Survival of *Lupinus sulphureus* ssp. *kincaidii* transplants at Isabelle was not affected by application of fertilizer or nodulating bacteria in 2001-2004 (0.15<*P*<1; Figure 16). Application of nodulating bacteria weakly affected flowering response in 2003 (*P*=0.08) and 2004 (*P*=0.07), but no other significant effects were observed (0.19<*P*<0.92; Figure 17). The 2000 data could not be analyzed by logistic regression.

(a)

(b)

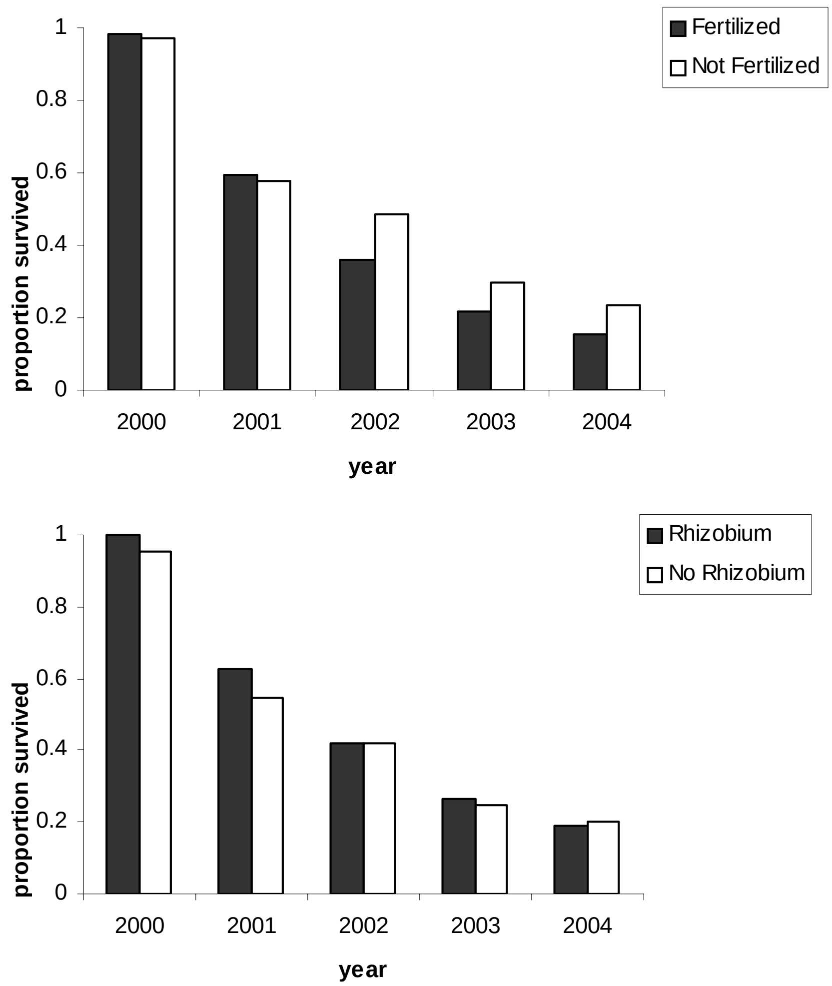
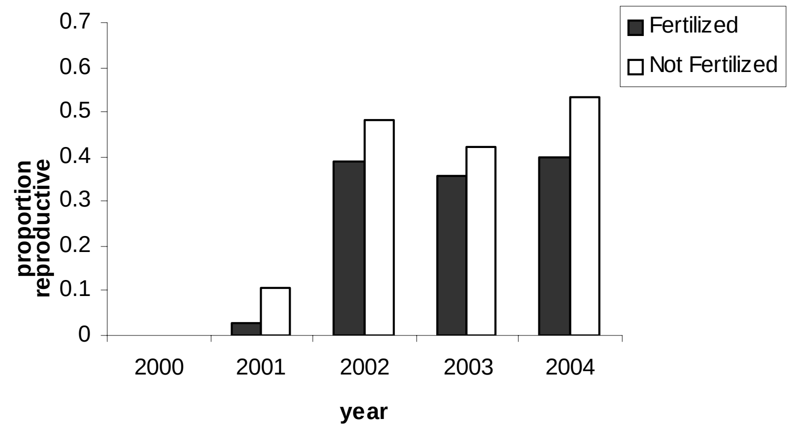


Figure 16. Proportion of transplants of *Lupinus sulphureus* ssp. *kincaidii* that survived in 2000-2004 at Isabelle when (a) fertilized or not and (b) nodulating bacteria was applied or not.

(a)



(b)

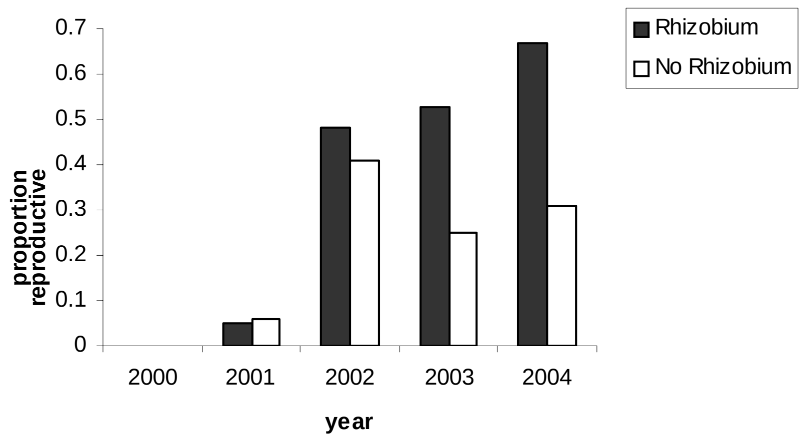


Figure 17. Proportion of transplants of *Lupinus sulphureus* ssp. *kincaidii* that were reproductive in 2000-2004 at Isabelle when (a) fertilized or not and (b) nodulating bacteria was applied or not.

A summary of transplant measurement data in 2000-2004 is presented in Table 16. A significant interaction between the treatments was observed in mean maximum width in 2002 (P=0.03). Maximum width was weakly affected by rhizobium application in 2003 (P=0.06). Mean perpendicular width was weakly affected fertilizer in 2000 (P=0.05) and 2002 (P=0.09), with a weak interaction between the treatments in 2002 (P=0.06). Perpendicular width was weakly affected by rhizobium in 2000 (P=0.07) and 2003 (P=0.07). The mean number of leaves per transplant was significantly greater for fertilized transplants in 2000 (P=0.0008), with a weak effect in 2002 (P=0.07; Figure 18). The number of leaves in 2003 was significantly greater for plants treated with nodulating bacteria (P=0.01). No other significant effects were observed ($0.13<P<0.97$). The total number of Fender's blue butterfly eggs observed on the transplants was 1 in 2001, 5 in 2002, 1 in 2003, and 57 in 2004 and was not affected by treatments ($0.12<P<0.61$).

Table 16. Mean measurements (with 95% confidence intervals) recorded for *Lupinus sulphureus* ssp. *kincaidii* transplants in 2000-2004 at Isabelle that received fertilizer, nodulating bacteria, both, or neither at the time of transplanting. n=32 for each treatment combination. (*denotes significance at the 0.05 level; **denotes significance at the 0.01 level; †denotes weak effect (0.05<*P*<0.1))

	Maximum width (cm)					Perpendicular width (cm)				
	2000	2001	2002*	2003†	2004	2000†	2001	2002†	2003†	2004
Fertilizer only	18.39 (16.36-19.43)	25.00 (20.48-29.52)	39.60 (30.06-49.14)	36.17 (19.94-52.40)	29.03 (26.50-31.56)	12.55 (10.68-14.42)	20.94 (16.76-25.12)	30.40 (28.14-32.66)	31.50 (17.21-45.79)	23.36 (20.83-25.90)
Rhizobium only	17.41 (15.41-19.41)	23.11 (18.85-27.37)	33.81 (26.27-41.35)	42.78 (29.53-56.03)	41.65 (39.22-44.08)	12.41 (10.57-14.25)	18.61 (14.67-22.55)	24.85 (22.65-27.05)	37.78 (26.11-49.45)	36.22 (33.78-38.66)
Fertilizer & rhizobium	18.78 (16.78-20.78)	25.80 (21.76-29.84)	49.67 (39.61-59.73)	57.50 (41.27-73.73)	29.17 (26.64-31.70)	14.72 (12.88-16.56)	20.90 (17.16-24.64)	40.42 (38.14-42.70)	47.33 (33.04-61.62)	20.26 (17.72-22.79)
No fertilizer or rhizobium	16.90 (14.80-19.00)	25.88 (21.36-30.40)	44.29 (36.23-52.35)	32.33 (16.10-48.56)	31.21 (28.82-33.61)	11.14 (9.20-13.08)	21.13 (16.95-25.31)	31.09 (28.88-33.30)	27.50 (13.21-41.79)	21.31 (18.91-23.72)

Table 16 (continued)

	Mean number of leaves					Mean number of inflorescences				
	2000**	2001	2002†	2003**	2004	2000	2001	2002	2003	2004
Fertilizer only	13.07 (10.87-15.27)	40.23 (37.76-42.70)	116.62 (114.03-119.21)	63.31 (60.46-66.16)	61.80 (58.20-65.40)	0	0.00 (-1.23-1.23)	0.94 (-1.07-2.95)	0.74 (-1.77-3.25)	0.69 (-1.58-2.96)
Rhizobium only	9.67 (7.47-11.87)	26.72 (24.28-29.16)	68.05 (65.61-70.49)	135.68 (133.02-138.34)	146.40 (143.11-149.67)	0	0.09 (-1.13-1.31)	0.87 (-0.88-2.62)	1.60 (-0.56-3.76)	2.31 (0.28-4.33)
Fertilizer & rhizobium	15.27 (13.07-17.47)	36.95 (34.54-39.36)	152.52 (149.89-155.15)	235.03 (232.07-237.99)	48.49 (44.88-52.09)	0	0.05 (-1.16-1.26)	1.14 (-0.93-3.21)	1.95 (-0.76-4.66)	0.82 (-1.45-3.09)
No fertilizer or rhizobium	9.40 (7.19-11.61)	42.04 (39.57-44.51)	99.06 (96.58-101.54)	62.76 (59.91-65.61)	37.96 (34.79-41.13)	0	0.15 (-1.08-1.38)	1.37 (-0.45-3.19)	0.62 (-1.89-3.13)	0.23 (-1.71-2.18)

Coble– *Lupinus*

Survival of lupine transplants at Coble did not significantly differ by treatment (0.97<*P*<1; Figure 18). The mean number of leaves per transplant did not significantly differ by treatments in 2003, but the interaction of the two variables was significant (Table 17). The mean number of leaves per transplant did not differ by treatment in 2004. The size of the transplants in 2004 did not significantly differ by treatment (0.10<*P*<0.84). Overall, mean maximum width was 20.63 cm, perpendicular width was 15.17 cm, and one inflorescence and one Fender's blue butterfly egg were observed

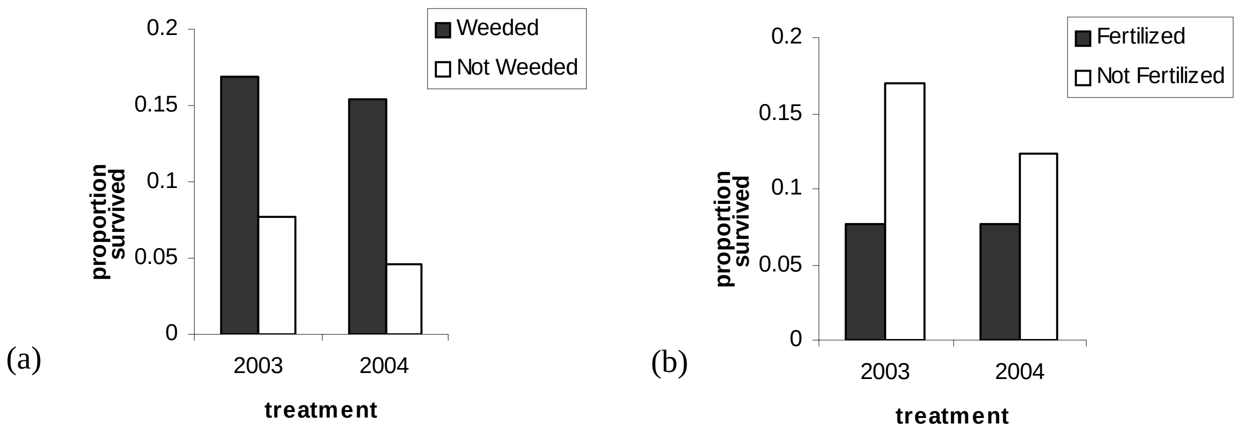


Figure 18. Proportion of *Lupinus sulphureus* ssp. *kincaidii* transplants at Coble that survived in 2003 and 2004 by (a) weeding treatment and (b) fertilization treatment.

Table 17. Mean number of leaves (with 95% confidence intervals) per *Lupinus sulphureus* ssp. *kincaidii* transplant at Coble in 2003 and 2004. n=7 weeded/fertilized, 6 weeded/not fertilized, 7 not weeded/fertilized, 6 not weeded/not fertilized. (*denotes significance at the 0.05 level)

Year	Weeded, fertilized	Weeded, not fertilized	Not weeded, fertilized	Not weeded, not fertilized	P-value		
					Weeding treatment	Fertilization treatment	Inter-action
2003*	22.00 (14.09-29.91)	7.00 (0.55-13.45)	5.00 (-6.18-16.18)	12.33 (5.88-18.78)	0.22	0.40	0.045
2004	44.44 (41.82-47.07)	38.77 (36.02-41.52)	13.00 (9.48-16.52)	32.00 (28.47-35.52)	0.19	0.45	0.32

Beaver Run – *Aster*

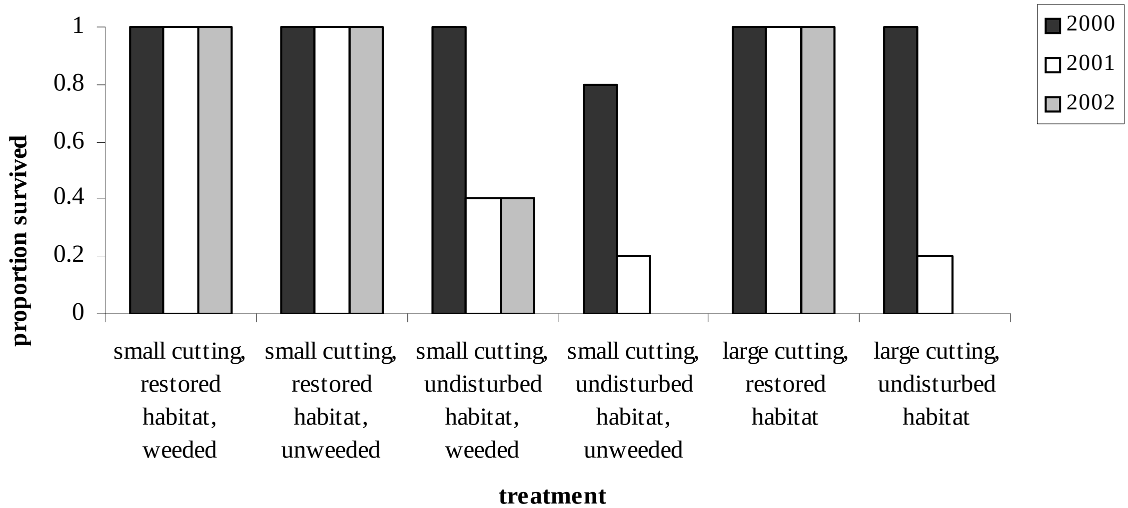
Spring Transplants

Survival was very high in the spring transplants of *Aster curtus* at Beaver Run (Figure 19). The proportion of transplants that survived in the restored habitat was greater overall than in the undisturbed habitat but could not be analyzed by logistic regression. The original size of the transplants had no apparent effect on survival. The majority of transplants that survived produced capitula in all years (Figure 20). No significant effects of treatments were observed in 2000 or 2001 (0.10<*P*<0.56) and data for other years could not be analyzed.

A summary of the measurement data for the transplants from 2000-2002 is shown in Table 18. The maximum and perpendicular widths and the height of the large cutting transplants were significantly greater in 2000 than those of the small transplants (*P*=0.001, 0.0002, and 0.02, respectively). The number of capitula per transplant in 2000 was also significantly greater in the large cutting transplants (*P*=0.002). Transplant height was significantly greater in the undisturbed habitat in 2001 (*P*=0.04). Transplants had significantly more capitula in the undisturbed habitat in 2001, both when all cutting sizes were included (*P*=0.001) and when the effects of weeding were included (*P*=0.02). All other variables were not significantly affected by the treatments (0.10<*P*<0.98).

During the summer of 2002, the undisturbed area at Beaver Run was mowed and the transplants located there can no longer be monitored. Data was taken on the transplants located in the restored area in September 2002, however, and provides a more accurate account of the maximum size of the transplants in that year. The height of the large cutting transplants (37.80±6.00 cm) was significantly greater than the small transplants (28.83±3.87 cm; *P*=0.03). Mean size of the transplants was 40.20 by 29.67 cm**,** number of stems was 16.51, and number of inflorescences was 42.47, none of which significantly differed by treatment (0.26<*P*<0.91).

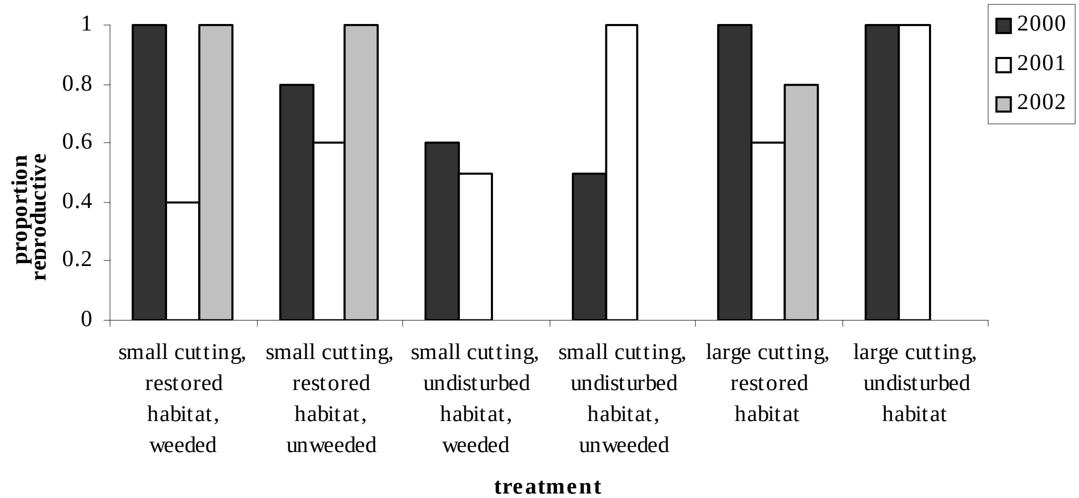
The mean maximum width of the transplants from large cuttings was significantly greater (111.33±28.41 cm) than the transplants from small cuttings (52.50±9.35 cm) in 2004 (*P*=0.0003). Mean perpendicular width of the large cutting transplants was also significantly greater in 2004 (large cutting: 78.33±27.91 cm; small cutting: 37.20±9.26 cm; *P*=0.004). No other significant effects were observed (0.12<*P*<0.95). In 2003, the mean maximum width of the transplants was 42.93±6.19 cm, perpendicular width was 27.47±7.28 cm, height was 34.00±3.71 cm, number of stems per transplant was 28.13±10.01, and number of capitula per transplant was 73.07±30.98. In 2004, the mean maximum width of the transplants was 66.08±16.68 cm, perpendicular width was 46.69±13.25 cm, height was 31.85±5.79 cm, number of stems was 92.00±73.22, and number of capitula was 272.46±298.78.



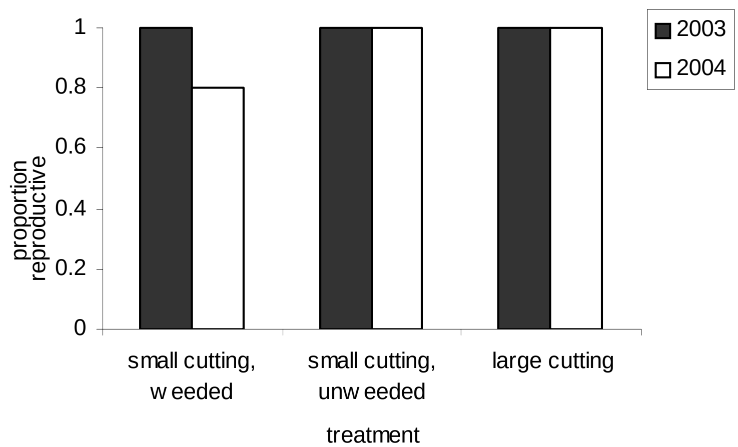
(a)

(b)

Figure 19. Proportion of *Aster curtus* spring transplants that survived at Beaver Run in (a) 2000-2002 and (b) 2003-2004. Crossed treatments included two sizes of cuttings, restored and undisturbed habitat, and weeded or unweeded plots for the small cuttings. Plots in undisturbed habitat mowed in 2002; data no longer available. n=5 for each treatment combination.



(a)



(b)

Figure 20. Proportion of *Aster curtus* spring transplants that were reproductive at Beaver Run in (a) 2000-2002 and (b) 2003-2004. Crossed treatments included two sizes of cuttings, restored and undisturbed habitat, and weeded or unweeeded plots for the small cuttings. Plots in undisturbed habitat mowed in 2002; data no longer available. n=5 for each treatment combination.

Table 18. Mean measurements (with 95% confidence intervals) collected for *Aster curtus* spring transplants of different original sizes placed in two habitat types at Beaver Run in 2000-2002. The immediate area around small cuttings was weeded or not. Number of stems was not recorded in 2000 and 2001; number of capitula in 2002 was not recorded before plots in the undisturbed habitat were mowed. n=5 for each treatment combination. (*denotes significance at the 0.05 level; **denotes significance at the 0.01 level)

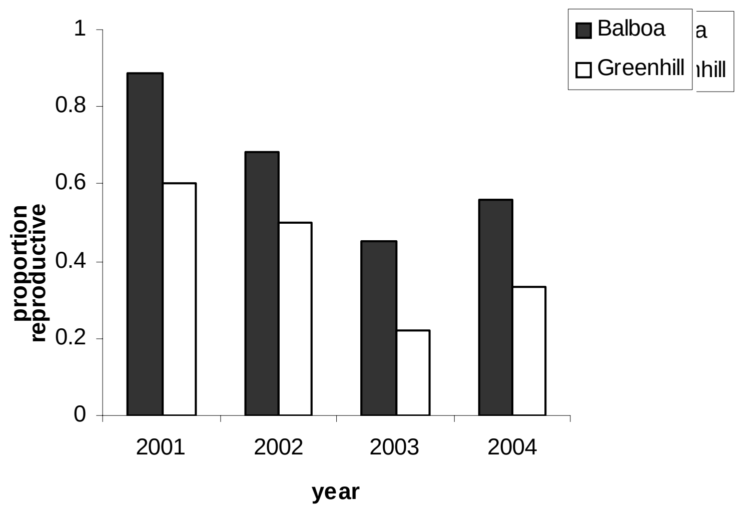
	Maximum width (cm)			Perpendicular width (cm)			Height (cm)			Number of stems	Number of capitula	
	2000**	2001	2002	2000**	2001	2002	2000*	2001*	2002*	2002	2000**	2001**
Small cutting, restored habitat, weeded	11.60 (6.28-16.92)	24.60 (17.04-32.16)	31.40 (19.63-43.17)	7.20 (5.51-8.89)	15.20 (9.61-20.79)	26.00 (15.19-36.81)	17.40 (7.91-26.89)	23.00 (15.28-30.72)	20.80 (17.74-23.86)	17.20 (10.04-24.36)	8.20 (2.31-14.09)	17.60 (-3.85-39.05)
Small cutting, restored habitat, unweeded	9.60 (7.23-11.97)	22.00 (12.46-31.54)	30.60 (22.46-38.74)	6.60 (4.40-8.80)	14.20 (8.15-20.25)	19.60 (12.04-27.16)	16.00 (3.71-28.29)	21.00 (13.56-28.44)	21.20 (15.82-26.58)	16.20 (9.34-23.06)	20.80 (-8.69-50.29)	15.60 (-0.88-32.08)
Small cutting, undisturbed habitat, weeded	11.00 (3.72-18.28)	20.50 (-1.19-42.19)	19.00 (-0.83-38.83)	6.80 (3.44-10.16)	18.50 (-1.95-38.95)	11.00 (-0.16-22.16)	16.40 (-1.48-34.28)	30.00 (17.60-42.40)	24.50 (12.72-36.28)	6.00 (2.28-9.72)	16.00 (-12.46-44.46)	42.50 (-10.18-95.18)
Small cutting, undisturbed habitat, unweeded	7.50 (5.18-9.82)	46.00 (18.11-73.89)	-	6.25 (4.44-8.06)	28.00 (6.93-49.07)	-	13.75 (-1.34-28.84)	37.00 (25.84-48.16)	-	-	25.25 (-15.58-66.08)	102.00 (63.57-140.43)
Large cutting, restored habitat	16.20 (11.04-21.36)	29.20 (17.87-40.53)	41.80 (29.95-53.65)	12.20 (7.26-17.14)	18.80 (10.18-27.42)	29.60 (15.54-43.66)	19.40 (15.86-22.94)	29.80 (22.56-37.04)	27.60 (26.27-28.93)	23.20 (12.23-34.17)	31.80 (-9.17-72.77)	22.20 (-1.81-46.21)
Large cutting, undisturbed habitat	22.20 (13.58-30.82)	30.00 (22.38-37.62)	-	15.80 (10.71-20.89)	26.00 (23.91-28.09)	-	38.00 (31.02-44.98)	44.00 (37.05-50.95)	-	-	112.00 (34.62-189.38)	122.00 (105.83-138.17)

Autumn Transplants

Survival was very high for the autumn transplants of *Aster curtus* at Beaver Run, with 80% of transplants surviving to 2004 (Figure 21). Survival of transplants from Balboa was significantly greater than transplants from Greenhill in 2002 ($P=0.04$) and 2003 ($P=0.04$), with a weak effect in 2004 ($P=0.06$). Flowering responses appeared greater in transplants from Balboa and fertilized transplants in all years (Figure 22). Transplants from Balboa produced a significantly greater proportion of reproductive plants in 2001($P=0.008$), with a weak interaction effect between treatments ($P=0.08$). Fertilized transplants produced a significantly greater proportion of reproductive plants in 2004 ($P=0.04$). No other significant effects were observed ($0.19<P<0.85$) and the 2001 survival data could not be analyzed by logistic regression.

A summary of transplant measurements in 2001-2004 is presented in Table 19. The mean maximum width of the fertilized transplants was significantly greater than the unfertilized transplants in 2003 ($P=0.048$). Mean perpendicular width of the transplants from Balboa was significantly greater than transplants from Greenhill in 2001 ($P=0.02$). Mean perpendicular width of the fertilized transplants was significantly greater than the unfertilized in 2003 ($P=0.041$) and 2004 ($P=0.02$), with a weak interaction effect between treatments in 2004 ($P=0.09$). Mean height of the transplants from Balboa was significantly greater than transplants from Greenhill in 2001 ($P=0.047$). Mean height of the fertilized transplants was significantly greater than the unfertilized in 2001 ($P=0.01$), 2002 ($P=0.009$), 2003 ($P=0.001$), and 2004 ($P=0.009$). A weak interaction effect on the number of stems per transplant was observed between source population and fertilization treatment in 2003 ($P=0.08$). No other significant effects were observed ($0.12<P<0.95$).

(a)



(b)

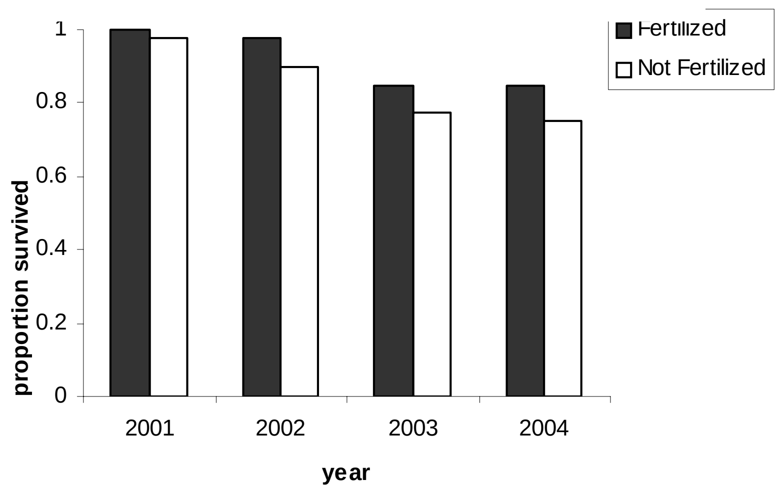


Figure 21. Proportion of
Aster curtus autumn transplants that survived in 2001-2004 at Beaver Run by (a) seed source and (b) treatment.

(a)

(b)

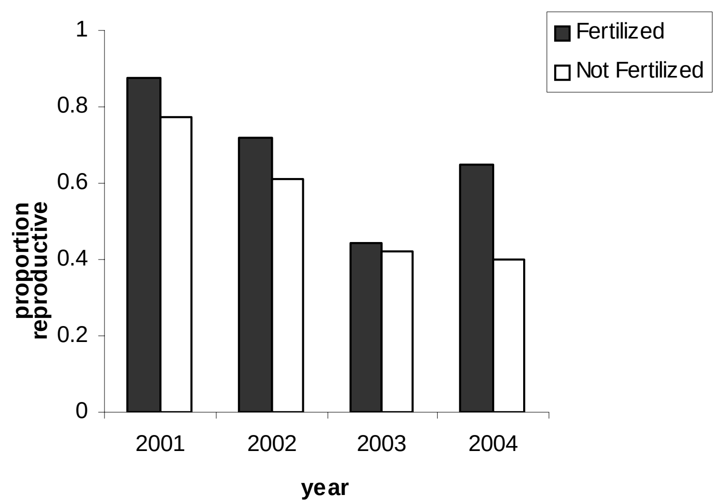


Figure 22. Proportion of *Aster curtus* autumn transplants that were reproductive at Beaver Run in 2001-2004 by (a) seed source and (b) treatment.

Table 19. Mean measurements (with 95% confidence intervals) collected for fertilized and unfertilized *Aster curtus* autumn transplants at Beaver Run from two seed sources in 2001-2004. n=33 Balboa/fertilized, 29 Balboa/unfertilized, 7 Greenhill/fertilized, and 8 Greenhill/unfertilized. (*denotes significance at the 0.05 level; **denotes significance at the 0.01 level; †denotes weak effect (0.05<*P*<0.1))

Treatment	Maximum width (cm)				Perpendicular width (cm)				Height (cm)			
	2001	2002	2003*	2004	2001*	2002	2003*	2004*	2001**	2002**	2003**	2004**
Balboa, fertilized	19.38 (16.53-22.23)	27.52 (23.50-31.54)	29.42 (23.87-34.97)	46.07 (36.44-55.69)	11.75 (9.88-13.62)	16.65 (13.55-19.75)	11.68 (9.36-14.00)	24.533 (19.52-29.55)	26.22 (22.57-29.87)	25.52 (22.11-28.93)	21.08 (17.73-24.43)	21.90 (18.28-25.52)
Balboa, unfertilized	17.64 (14.59-20.69)	24.35 (19.69-29.01)	25.09 (19.05-31.13)	35.68 (24.44-46.92)	12.82 (10.82-14.82)	16.61 (13.01-20.21)	20.73 (17.72-23.74)	20.73 (14.87-26.58)	22.75 (18.84-26.66)	19.48 (15.52-23.44)	15.09 (11.45-18.73)	15.95 (11.72-20.19)
Greenhill, fertilized	13.86 (7.77-19.95)	26.33 (17.20-35.46)	39.00 (24.84-53.16)	52.00 (25.65-78.35)	9.29 (5.30-13.28)	14.67 (7.63-21.71)	9.36 (7.01-11.71)	30.75 (17.02-44.48)	24.57 (16.76-32.38)	25.83 (18.07-33.59)	25.25 (16.71-33.79)	23.50 (13.58-33.42)
Greenhill, unfertilized	10.00 (3.91-16.09)	20.50 (11.37-29.63)	21.00 (6.84-35.16)	28.40 (4.83-51.97)	7.43 (3.44-11.42)	13.83 (6.79-20.87)	6.55 (3.54-9.56)	9.60 (-2.68-21.88)	11.71 (3.90-19.52)	15.17 (7.41-22.93)	8.50 (-0.04-17.04)	9.60 (0.72-18.48)

Table 19. (continued)

Treatment	Number of stems				Number of capitula			
	2001	2002	2003†	2004	2001	2002	2003	2004
Balboa, fertilized	5.78 (4.91-6.65)	9.45 (7.50-11.40)	9.15 (6.65-11.65)	10.40 (8.06-12.75)	49.19 (34.95-63.43)	21.39 (13.39-29.39)	6.96 (1.84-12.08)	4.45 (2.64-6.27)
Balboa, unfertilized	7.43 (6.50-8.36)	10.57 (8.31-12.83)	10.05 (7.33-12.77)	10.24 (7.82-12.66)	46.82 (31.60-62.04)	16.57 (7.28-25.86)	8.41 (2.84-13.98)	2.13 (0.14-4.12)
Greenhill, fertilized	6.71 (4.86-8.56)	7.00 (2.57-11.43)	13.75 (7.38-20.12)	14.89 (11.68-18.09)	47.43 (16.99-77.87)	16.33 (-1.85 - 34.51)	14.25 (1.20-27.30)	2.50 (-1.71-6.71)
Greenhill, unfertilized	6.14 (4.29-7.99)	8.33 (3.90-12.76)	5.75 (-0.62-12.12)	5.24 (2.20-8.29)	11.57 (-18.87-42.01)	7.83 (-10.35 - 26.01)	0.00 (-13.05-13.05)	0.55 (-3.15-4.26)

SUMMARY AND DISCUSSION

Direct seeding vs. transplanting

The success of seeding and transplanting differed for each of the species studied. Establishment from seed was very low for *Aster curtus* and *Erigeron decumbens*, moderate for *Horkelia congesta*, highest for *Lomatium bradshawii*, and ranged from moderate to high for *Lupinus sulphureus* ssp. *kincaidii*. Transplant survival also differed among species, as well as among planting sites, with ranges of approximately 20-80% survival for *A. curtus*, 20% for *E. decumbens*, 30-40% for *H. congesta*, 25-50% for *L. bradshawii*, and 0-35% for *L. sulphureus* ssp. *kincaidii* over the duration of the study. These results suggest that seeding can be a more successful method of reintroduction or augmentation for some species while transplanting is better for others.

Aster curtus seedling establishment rates were very low in seeded plots at both Greenhill Road and Beaver Run: 1.2% in the first, 0.4-1% in the second, 1.4-4.8% in the third, 0.6-1.8% in the fourth, and 1.2-2.4% in the fifth year after seeding. Approximately 23% of transplants at Greenhill Road and 81% of those at Beaver Run survived to 2004 (note: does not include transplants at Beaver Run that were located in the plots mowed in 2002). Approximately 9% of the original transplants at Greenhill Road and 48% of the original transplants at Beaver Run were reproductive in 2004. The size of the spring transplants at Beaver Run tended to be greater when larger cuttings were transplanted, though the effects were only significant on widths in 2000 and 2004 and height in 2000 and 2002. A weak interaction effect between cutting size and transplanting habitat was observed on transplant height in 2000, with large cuttings having greater height in the undisturbed habitat and small cuttings in the restored habitat. Transplanting *ex situ* cultivated material appears to be the most effective propagation method for *A. curtus*, especially considering its often low viable seed production.

Direct seeding with *Erigeron decumbens* produced very few seedlings at Greenhill Road: 0.33% establishment in the first, 0.17% in the second and third, 0.33% in the fourth, and 0.50% in the fifth year after seeding. Approximately 20% of transplants in the Greenhill Road 20x30 m grid and 19% in the Greenhill arrays survived until 2004. Approximately 16% of the original transplants in the 20x30 m grid and 13% of the original transplants in the arrays were reproductive in 2004. One seedling was observed near a transplant in the arrays in 2004, thus the transplants are producing some viable seed. Vole herbivory was intense in the 20x30 m grid in 2001 and heavily damaged 39% of the transplants, thus transplanting may be more effective than observed in this study when such herbivory is less.

Seeding *Horkelia congesta* produced modest numbers of plants at Greenhill Road, Balboa, and Rosy: 1.5-10.0% establishment in the first, 1.9-5.4% in the second, 1.9-6.0% in the third, 1.5-4.4% in the fourth, and 2.2-4.1% in the fifth year after seeding. The percentages of reproductive plants in seeding plots were: 5% in 2001, 33% in 2003, and 50% in 2004 at Greenhill Road; 1% in 2001, none in 2002, 2% in 2003, and 5% in 2004 at Rosy and Balboa. Approximately 38% of *H. congesta* transplants in the Greenhill Road 20x30 m grid and 32% of the transplants in the Greenhill arrays survived until 2004. Approximately 29% of the original transplants in the

20x30 m grid and 22% of the original transplants in the arrays were reproductive in 2004. This species had relatively high germination under controlled conditions and very high survival in pots in a greenhouse, suggesting that outplanting may be more effective than seeding. The presence of seedlings in 2003 and 2004 in both transplanted areas suggests that the transplanted populations may persist even without further augmentation.

Direct seeding appeared to be a fairly efficient method of establishing seedlings of *Lomatium bradshawii* at Greenhill Road, Balboa, and Rosy: 27.8-30.4% establishment in the first, 11.6-21.0% in the second, 17.2-23.8% in the third, 20.2-26.0% in the fourth, and 19.6-25.0% in the fifth year after seeding. The percentages of reproductive plants in seeding plots were: 3.5% in 2002, 13.5% in 2003, and 32.7% in 2004 at Greenhill Road; 2.6% in 2003 and 6.6% in 2004 at Balboa and Rosy. In 2004, four of the plants in seeding plots at Greenhill Road and one at Rosy and Balboa were seedlings, suggesting that the seeded populations are producing viable seed. Approximately 27% of the transplants in the Greenhill Road 20x30 m grid and 54% of the transplants at Rosy and Balboa survived until 2004. Approximately 13% of the original transplants at Greenhill Road and 16% of the original transplants at Rosy and Balboa were reproductive in 2004. Transplants at Rosy generally had greater survival and flowering response than those at Balboa, though the difference was not significant. Thus, both methods of propagation appear suitable for augmenting or establishing populations of this species.

Seeding *Lupinus sulphureus* ssp. *kincaidii* at Isabelle and Coble appeared effective: 7.7-25.7% establishment in the first, 8.9-12.4% in the second, 4.9-8.4% in the third, 4.9% in the fourth, and 5.6% in the fifth year after seeding. A weakly positive effect of seed scarification was observed on the number of leaves per plant in seeding plots at Isabelle in 2003, but scarification of seeds otherwise showed no impact on the success of direct seeding. The percentages of reproductive plants in the seeding plots at Isabelle were 4% in 2001, 49% in 2002, 45% in 2003, and 29% in 2004 (excluding the plots added in 2003; 0.87% of the plants in the new plots were reproductive in 2004). None of the plants in Coble seeding plots were reproductive by 2004. The success of transplanting differed by site, with 20% of the transplants at Isabelle, 36% at Oxbow West, and 10% at Coble surviving to 2004. Approximately 9% of the original transplants at Isabelle and 0.6% of the original transplants at Coble were reproductive in 2004 (no reproductive plants at Oxbow West). No transplants survived to 2002 at Balboa or 1135 and only transplants on the small hill survived past 2002 at Greenhill Road (80% survived to 2004). Fender's blue butterfly eggs were observed in seeding plots at Isabelle and on transplants at Isabelle, Oxbow West, and Coble, with numbers drastically increasing from 2001 to 2004, suggesting that both reintroduction methods provide satisfactory habitat for the butterfly. Generally, seeding appears more effective for establishing lupine, but success may largely depend upon the site quality.

Overall, transplanting appeared more effective than seeding for *A. curtus*, *E. decumbens*, and *H. congesta* reintroduction and/or augmentation, while seeding appeared most effective for *L. bradshawii* and *L. sulphureus* ssp. *kincaidii*. Transplanting did generally yield more plants and greater reproduction in the short-term, but required greater time and effort than seeding. The availability of seeds of each species also impacts the efficiency of seeding. Survival rates within both seeded and transplanted populations tended to differ among the experimental sites, thus we would recommend using multiple sites with habitat characteristics as similar as possible to the wild population's habitat.

Comparison of source populations

Source population significantly affected survival of autumn *Aster curtus* transplants at Beaver Run to 2002 and 2003 and weakly affected survival to 2004, with transplants from Balboa having greater survival than those from Greenhill. Source population significantly affected the proportion of autumn transplants that were reproductive at Beaver Run in 2001. A weak interaction effect on flowering response occurred between source population and fertilization treatment at Beaver Run in 2001. The perpendicular width and height of transplants at Beaver Run in 2001 and the perpendicular width and height of transplants at Greenhill in 2001 was significantly greater for transplants from Balboa. There was a weak interaction effect between source population and fertilization treatment on number of stems per transplant at Beaver Run in 2003, with transplants from Balboa having more stems when unfertilized and transplants from Greenhill having more stems when fertilized.

A weak effect of source population on flowering response of *Erigeron decumbens* transplants in the Greenhill Road 20x30 m grid was observed in 2001 and 2003, with transplants from Fisher Butte and Oxbow producing a greater proportion of reproductive plants than transplants from Greenhill. A weak interaction effect on survival in the 20x30 m grid was observed between source population and planting season in 2001.

The Fisher Butte seed source had a weakly positive effect on survival to 2003 of *Horkelia congesta* transplants in the Greenhill Road 20x30 m grid while the Greenhill seed source had a weakly positive effect on flowering response in 2004. A significant interaction effect between source population and planting season was observed on maximum width and height of transplants in the 20x30 m grid in 2001 (autumn was better for Fisher Butte transplants, spring for Greenhill transplants). A weak effect of source population was observed on perpendicular width of transplants in the 20x30 m grid in 2004, with transplants from Fisher Butte having a greater perpendicular width.

Source population affected transplants of each of these species to some extent but only significantly affected survival of *A. curtus* transplants at Beaver Run, suggesting that, while source population may sometimes affect reintroduction success, it is not the most important factor. The results also suggested that transplants placed within the same site as their source population do not always have greater odds of survival than those from other sources. Therefore, we recommend using multiple seed sources in any reintroduction or augmentation effort to maximize the potential for success as well as the genetic diversity of the new population.

Effects of competition

Seedling establishment of *Aster curtus* at Beaver Run was not affected by weeding. Only one seedling was established in the undisturbed area (out of 500 seeds), while establishment was 2.2% in the restored area. In the Greenhill Road seeding plots, significantly more *A. curtus* plants were observed in the weeded plots in 2003 than in unweeded plots and a similar, though weak, effect of weeding was observed in 2004. *A. curtus* transplants at Beaver Run were not affected by weeding, but the height and number of capitula per transplant in the undisturbed habitat in 2001 was greater than in the restored habitat. Vegetative cover in the Greenhill Road 20x30 m grid positively affected transplant survival to 2003.

Seedling establishment of *Erigeron decumbens* only occurred in the weeded seeding plots at Greenhill Road, though this was not statistically significant. Vegetative cover had a weakly negative effect on flowering response of transplants in the Greenhill Road 20x30 m grid in 2003.

The number of *Horkelia congesta* plants was significantly greater in the weeded than the unweeded seeding plots at Greenhill Road in 2002, with a weak effect in 2001, 2003, and 2004. Reproductive plants were observed solely in the weeded plots in 2001, 2003, and 2004 (only years in which information was recorded). Vegetative cover in the Greenhill Road 20x30 m grid had a significant positive effect on survival to 2004 of *H. congesta* transplants.

Seeding of *Lomatium bradshawii* was significantly more effective at Greenhill Road when the established vegetation was cleared (>30% mean seedling establishment in weeded plots and <14% in unweeded plots in 2000-2004). Vegetative cover in the Greenhill Road 20x30 m grid had a significant negative effect on survival to 2003 and 2004 of *L. bradshawii* transplants.

A weak interaction effect was observed on the number of inflorescences per plant in *Lupinus sulphureus* ssp. *kincaidii* seeding plots at Isabelle in 2002, with scarified seeds producing more inflorescences in unweeded plots and unscarified seeds producing more inflorescences in weeded plots. A significantly greater number of plants were observed in unweeded than weeded seeding plots at Coble in 2002-2004, with a significant interaction between weeding and seed scarification in 2004. The number of leaves per plot in 2004 followed the same trend. A significant interaction effect between weeding and fertilization treatment was observed on the number of leaves per transplant at Coble in 2003, with unfertilized transplants having more leaves in unweeded plots and fertilized transplants having more leaves in weeded plots.

Reducing competition from existing vegetation appeared to increase success of reintroducing or augmenting rare plant populations in some cases. The effects of competition appeared to vary by site and species, however, suggesting that pilot studies may be useful in determining which species would benefit from, and sites would require, vegetation clearing. Clearing competing vegetation was most beneficial when directly seeding *A. curtus*, *E. decumbens*, *H. congesta*, and *L. bradshawii*. In the Greenhill Road 20x30 m grid, competition had mixed effects on transplant survival, which may be partially explained by a weak correlation between vegetative cover and topographic position of the transplants, in which vegetative cover was often greater in high topographic positions than in low. Vegetative cover positively affected survival of *A. curtus* and *H. congesta* transplants, species that preferred high topographic positions, while it negatively affected survival of *L. bradshawii* transplants, a species that preferred low topographic positions. Thus, the effects of clearing competing vegetation on transplants of these species may differ from the effects of vegetative cover observed in this study.

Effects of fertilizer and other soil amendments

Survival to 2003 was significantly greater for unfertilized *Aster curtus* transplants in the Greenhill Road 20x30 m grid, with a similar trend for autumn transplants in 2004. Flowering response of transplants in the 20x30 m grid was somewhat greater for unfertilized transplants in 2004 and significantly greater for unfertilized tranplants in 2002, though only fertilized transplants were reproductive in 2001. Flowering response was significantly greater for fertilized transplants at Beaver Run in 2004. Fertilized transplants at Beaver Run were also significantly taller than unfertilized transplants in 2001-2004 and larger in 2003 (by maximum and perpendicular width) and 2004 (by perpendicular width only).

Survival of unfertilized *Erigeron decumbens* transplants in the Greenhill Road 20x30 m grid was significantly greater than fertilized transplants in 2001-2004. A significant interaction effect occurred between fertilization treatment and planting season in 2001 and 2002, with autumn transplant survival positively affected by fertilization. The fertilized *E. decumbens* transplants in the 20x30 m grid were significantly larger by maximum and perpendicular widths and height than the unfertilized transplants in 2000.

Survival of unfertilized *Horkelia congesta* transplants to 2004 in the Greenhill Road 20x30 m grid was significantly greater than fertilized transplants. The maximum and perpendicular widths of *H. congesta* transplants in the 20x30 m grid were significantly greater for fertilized transplants in 2001. A weakly positive effect of fertilizer was observed on maximum width of the transplants in the 20x30 m grid in 2003. A weak effect of soil amendments on number of inflorescences per plant in the seeding plots at Rosy and Balboa was observed in 2004, control treatment having the most, then compost, then mycorrhizae, and the fertilizer and compost+mycorrhizae treatments having none.

Survival of unfertilized *Lomatium bradshawii* transplants in the Greenhill Road 20x30 m grid was significantly greater than fertilized transplants in 2001 and 2002. An interaction between fertilizer treatment and planting season was observed in 2002-2004, however, with fertilizer positively affecting survival of autumn transplants in 2002 and 2003 and negatively affecting spring transplants in 2004. Fertilizer had a weakly positive effect on flowering response of transplants in the 20x30 m grid in 2003. Survival and flowering response of transplants at Balboa and Rosy were not significantly affected by soil amendments, although those treated with compost or both compost and mycorrhizae had the lowest long-term survival rate and those treated with mycorrhizae had the highest.

Treating transplants of *Lupinus sulphureus* ssp. *kincaidii* at Isabelle with rhizobium had a weakly positive effect on flowering response in 2003 and 2004. A significant interaction effect was observed on maximum width and a weak interaction effect on perpendicular width between fertilization and rhizobium treatments in 2002, with the largest transplants being those treated with both or neither soil amendment. Rhizobium treatment had a weakly positive effect on maximum and perpendicular widths in 2003. Fertilizer had a weakly positive effect on transplant perpendicular width in 2000 and 2002; rhizobium had a weakly positive effect in 2000. Fertilizer had a significant positive effect on the number of leaves per transplant in 2000 and a weakly positive effect in 2002; rhizobium had a significantly positive effect in 2003. Fertilization positively affected the number of leaves per transplant in the weeded transplanting plots at Coble in 2003.

The effects of soil amendments were varied–survival was generally greater for transplants without soil amendments, while transplant size and flowering response were often positively affected by soil amendments. For *A. curtus*, the effect of fertilizer on transplant size and reproduction appeared to differ between years and transplanting sites. A significant interaction between fertilization treatment and planting season affected survival of both *E. decumbens* and *L. bradshawii* transplants, with fertilizer only positively affecting survival of autumn transplants. The effects of fertilizer observed in this study may have been indirect, i.e. applying fertilizer can provide additional nutrients for competitors as well as the transplants, which is supported by the sites at which fertilizer had the most positive and negative effects and the interaction effect observed on transplants at Coble. Overall, soil amendments did not appear necessary for reintroduction success and could actually impede success in weedy sites.

Comparison of planting season

Both spring and autumn transplants of *Aster curtus* at Beaver Run had high survival rates. Survival to 2003 of *A. curtus* transplants planted in the Greenhill Road 20x30 m grid in autumn was significantly greater than those planted in spring. Planting in spring had a weakly positive effect on flowering response in the 20x30 m grid in 2004. Perpendicular width of spring transplants in the 20x30 m grid was significantly greater in 2001.

Survival of *Erigeron decumbens* transplants in the Greenhill Road 20x30 m grid planted in spring was significantly greater in 2001-2004 than those planted in autumn. Planting season had a weak effect on transplant height in 2004, with autumn transplants being taller than spring transplants.

Survival of *Horkelia congesta* spring transplants in the Greenhill Road 20x30 m grid was significantly greater in 2002-2004 than those planted in autumn. Planting in spring had a weakly positive effect on flowering response in the 20x30 m grid in 2004. Maximum width of the spring transplants was significantly greater than the autumn transplants in 2004.

Survival to 2003 and 2004 of *Lomatium bradshawii* transplants in the Greenhill Road 20x30 m grid was greater for those planted in autumn, but a significant interaction was observed between fertilizer and planting season. Survival to 2003 was greatest for fertilized autumn transplants, followed by unfertilized spring transplants. Survival to 2004 was greater for autumn transplants than those planted in spring, with fertilizer negatively affecting survival of spring transplants.

From these results, it appeared that spring was the best planting season for *E. decumbens* and *H. congesta* and autumn the best planting season for *A. curtus*. Autumn was also the best planting season for *L. bradshawii* but may only be so when fertilizer is applied.

Effects of topographic position
The topographic position of transplants, from wetlands vs. uplands to being within or outside of vernal pools, may influence their persistence. In the Greenhill Road 20x30 m grid, transplant survival was affected by topographic position for all four species. *Aster curtus* transplants outside of vernal pools had significantly greater survival to 2003 and 2004 than those within pools. Planting *Erigeron decumbens* outside of vernal pools had a weakly positive effect on transplant survival to 2003. *Horkelia congesta* transplants outside of vernal pools had significantly greater survival to 2003 than those within pools. *Lomatium bradshawii* transplants within vernal pools had significantly greater survival to 2003 and 2004 than those outside of pools. Though not statistically analyzed, the effects of topographic position on *Lupinus sulphureus* spp. *kincaidii* transplants were evident at Greenhill Road–no transplants in the main grid at the site survived to the third year but four of five transplants on the site's small hill survived to the fourth year, suggesting that lupine transplant survival is greater in more upland sites. These observations correlate with the preferred habitats for wild populations of these species and suggest that the odds of transplant survival can be increased if transplants are placed in habitat most similar to that in which they naturally occur.

Recommendations
Several factors were shown to affect survival of seeded and transplanted plants, providing us with recommendations for reintroduction and augmentation of these species, which are listed below.

- *A. curtus*: Transplant in fall in wetland sites outside of vernal pools. With this protocol, up to 42% of transplanted *Aster curtus* survived 4 years. Direct seeding is not recommended; it produced only 1-2 % establishment. Fertilizer reduced survivorship at one site but increased flowering at another. Overall, we recommend fertilizing only in low competition environments.

- *E. decumbens*: Transplant in spring in wetland sites outside of vernal pools without fertilizer. This protocol yielded establishment rates of up to 55% after 4 years. Direct seeding produced <0.5% establishment and is not recommended.

- *H. congesta*: Transplant without fertilizer in wetland sites outside of vernal pools in spring. Success rates with this method ranged from 38% to 83% survival after 4 years. Direct seeding can produce a few recruits; however seeding was only marginally effective (up to 4% establishment when combined with weeding).

- *L. bradshawii*: Seed in wetlands without fertilizer in fall after removing or reducing competing vegetation. This protocol produced up to 37% establishment after 4 years. Transplanting works well in fall without fertilizer, especially in wetter sites with weeds eliminated. However, the gain in establishment (40-70% after four years) may not outweigh the increased labor involved.

- *Lupinus sulphureus* ssp. *kincaidii*: Success rates for this species are variable, and likely depend on seasonal climate and local site characteristics such as abundance of weedy vegetation, soil type and hydrology, and soil microorganisms (mycorrhizae and/or *Rhizobium*). Our best recommendations to date are to seed in fall in upland sites with little competing vegetation, especially grasses and aggressive weeds. Transplanting may work, but only in well-restored native prairie with minimal weed densities, especially grasses and aggressive weeds. No fertilization is necessary but *Rhizobium* may increase flowering in the long term.

In addition to the species specific recommendations, we stress the importance of site selection and site preparation. Sites for reintroduction should be similar to habitats where the species currently thrives, and weed abundance should be kept low. Reintroducing species to multiple sites provides the best potential for species recovery.

All five of these rare species can be successfully reintroduced or increased in abundance using the protocols described above. Seedlings were observed near some *E. decumbens* and *H. congesta* transplants after four years and new seedlings have appeared in *L. bradshawii* seeding plots after five years, suggesting that viable seed can be produced in a new population within a short time period. Fender's blue butterfly eggs were observed on both seeded and transplanted populations of *L. sulphureus* ssp. *kincaidii*, thus both propagation methods produce acceptable lupine habitat for the butterfly.

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Appendix I

Site Documentation Packet